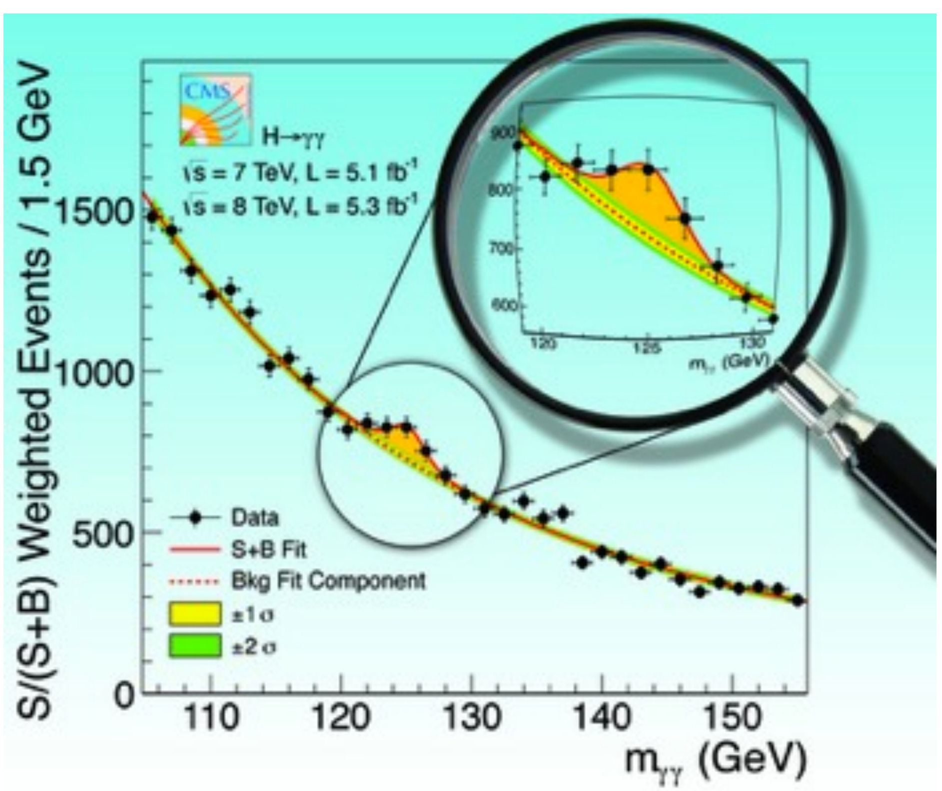
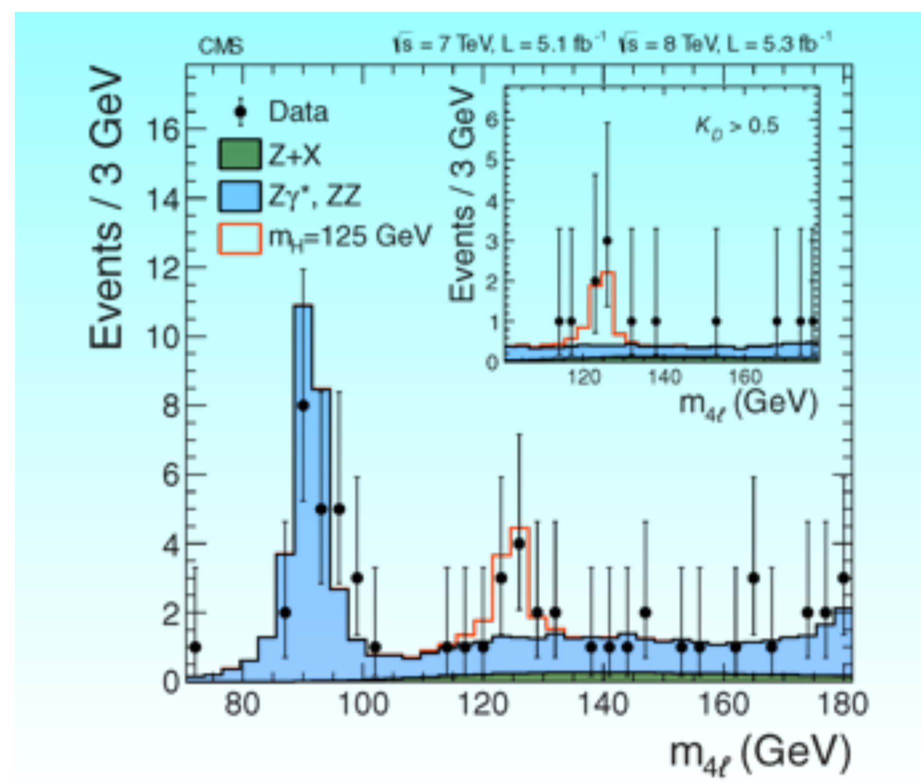
A future Higgs factory: CMS at LEP3

Markus Klute (MIT)

Fermilab Wine & Cheese Seminar
September 28th, 2012

Higgs physics after the discovery





We have it!

- We have something to celebrate!
- 5σ excess observed,
  5.8σ expected by CMS
- New state with mass of
  125.3 ± 0.6 GeV
- Confirmed by ATLAS
- Consistent with SM prediction
  - more data and more studies are needed to draw conclusions
- Physics Letters B 716 (2012) 1-29
  Physics Letters B 716 (2012) 30-61
- Going forward with two prong approach
  - characterize new particle
  - continue search for BSM physics in the Higgs sector

Chicago

Melbourne

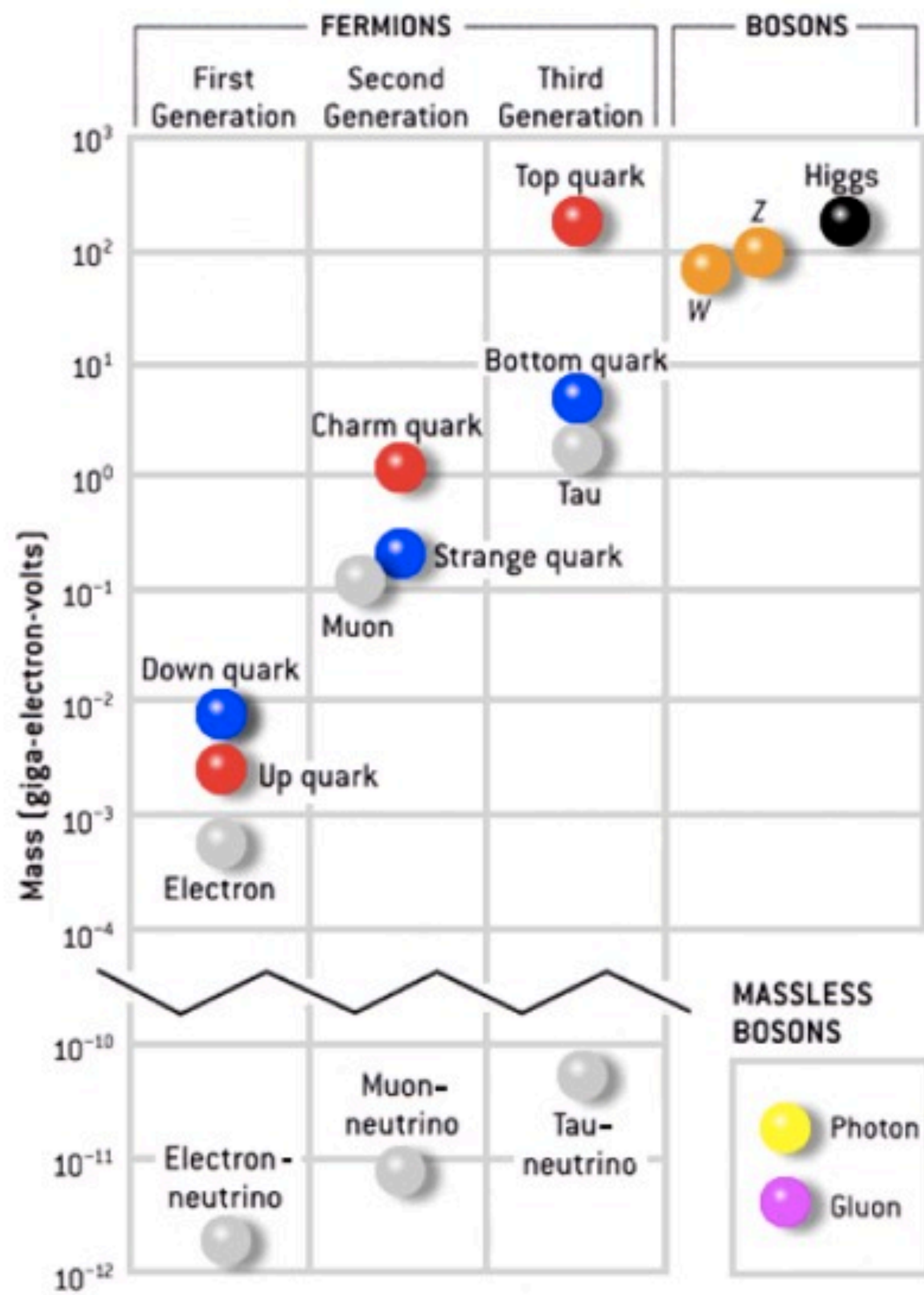
CERN

July 4th, 2012 celebration

Why is the Higgs boson interesting?

- Experiments have measured elementary particle masses
- Masses are not predicted by theory
- Mass span many orders of magnitude
- Electron is 350.000 times lighter than the top quark
- Neutrinos live on a different scale
- Photons and gluons are massless

- Why? How do particles acquire mass?
- Is there structure?
- Is this the full spectrum?
- Imagine a massless world

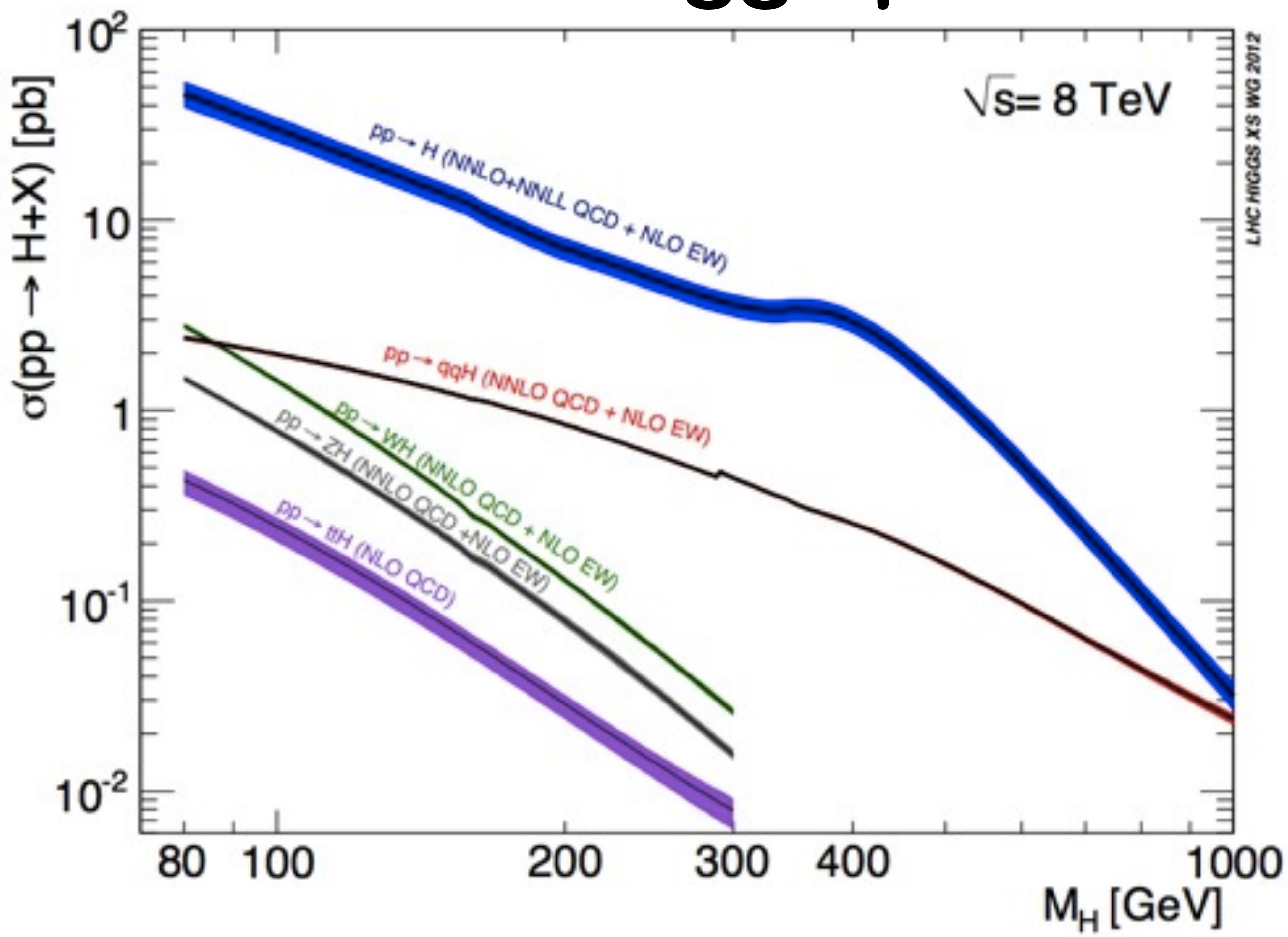


The Higgs Mechanism

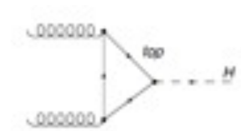
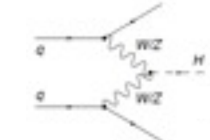
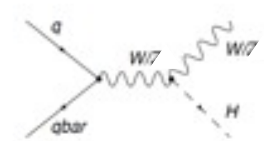
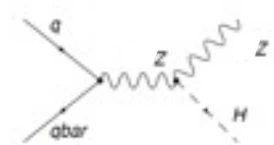
- Massless theory fixed by adding an extra field
    - the Higgs mechanism proposed ~1964
    - new Higgs boson is predicted
    - its mass is a free parameter, the only additional free parameter
- More complicate mechanism possible
    - non or more Higgs bosons
    - modified Higgs or particle sector
- Experimentally not confirmed - until July 4th 2012
- Unveiling the principle of mass creation of elementary particles
    - W, Z boson masses through electroweak symmetry breaking
    - Quark and charged lepton mass through Yukawa coupling with Higgs field

SM Higgs boson footprint at the LHC

Higgs production cross section



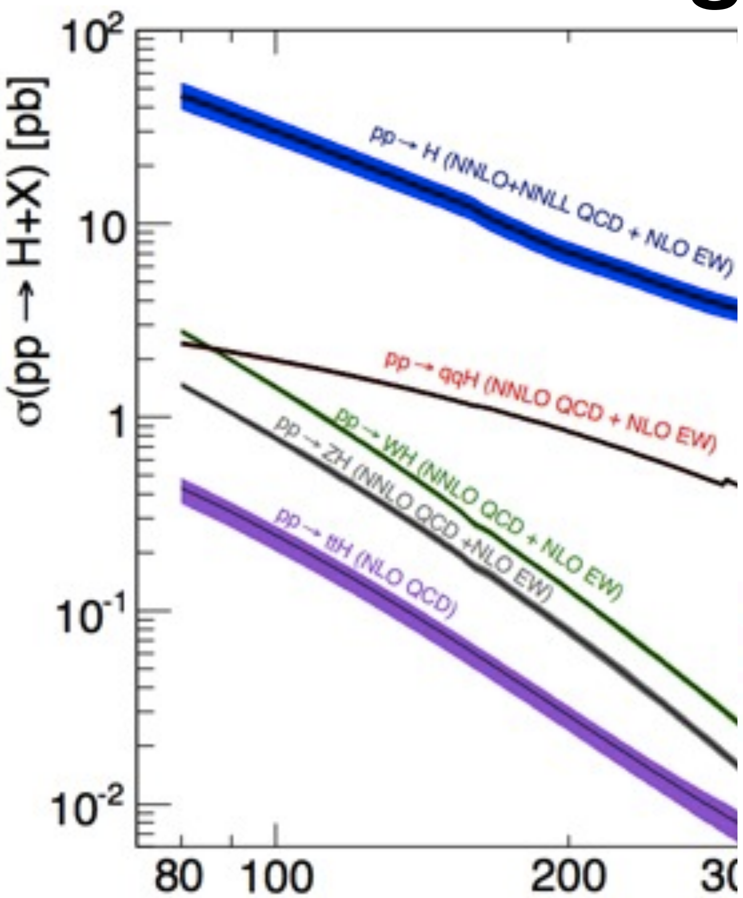
m_H = 125 GeV

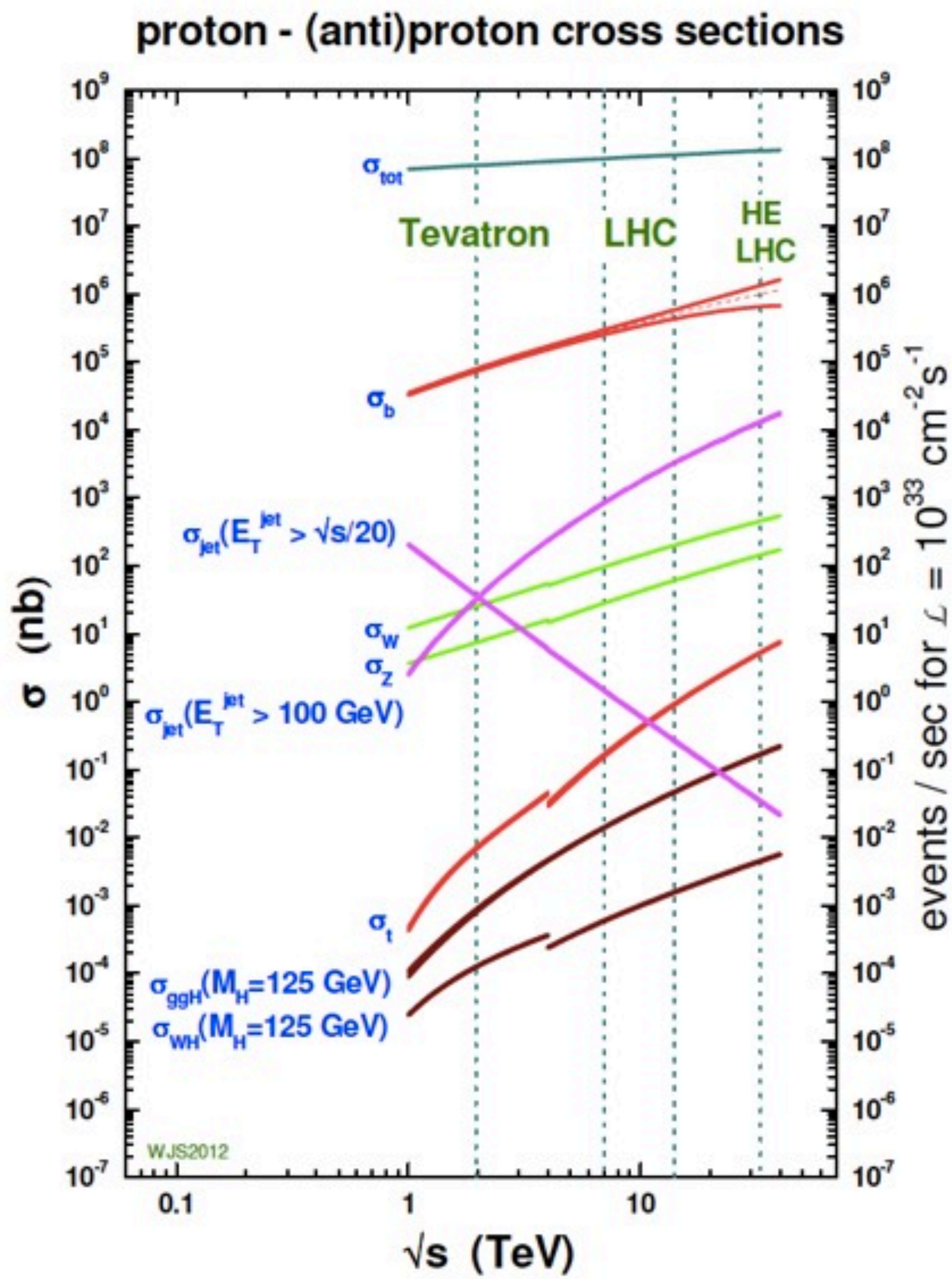
Process	Diagram	Cross section [fb]	Unc. [%]
gluon-gluon fusion		19520	15
vector boson fusion		1578	3
WH		697	4
ZH		394	5
ttH		130	15

- total cross section is 22 pb
- gluon-gluon fusion known at NNLO
- 5 different SM Higgs production mechanisms can be tested at the LHC
- ~1 M Higgs bosons produced in ATLAS and CMS
- LHC produces ~15 Higgs boson per minute
- buried in enormous backgrounds

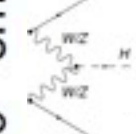
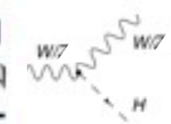
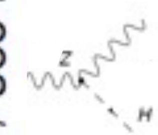
SM Higgs boson footprint at the LHC

Hig :ion





m_H = 125 GeV

gram	Cross section [fb]	Unc. [%]
	19520	15
	1578	3
	697	4
	394	5
	130	15

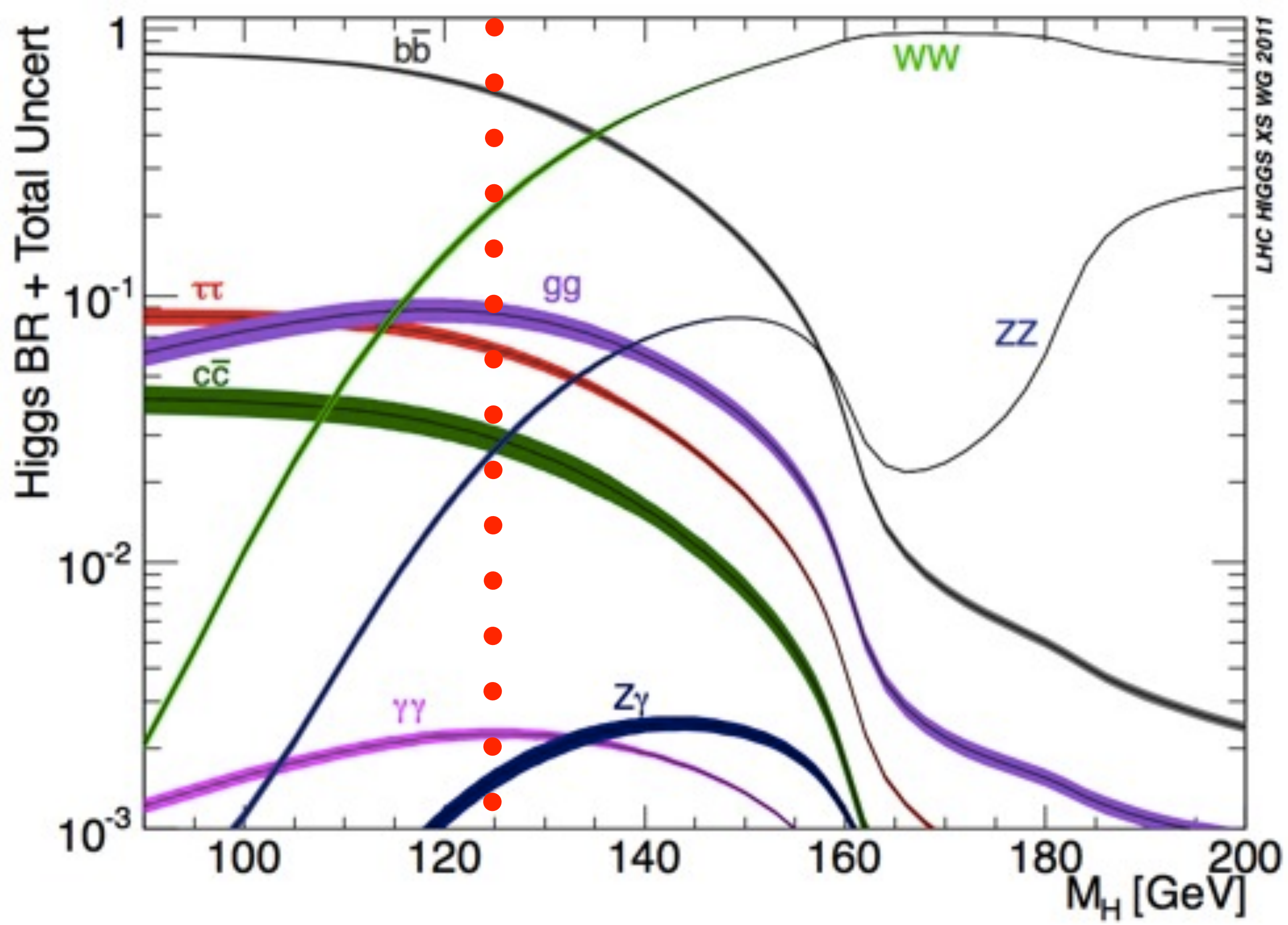
- total cross section is 2
- gluon-gluon fusion kno
- 5 different SM Higgs pı
- ~1 M Higgs bosons pro
- LHC produces ~15 Hig
- buried in enormous ba

HC

Markus Klute

SM Higgs boson footprint

Decays to fermions and bosons



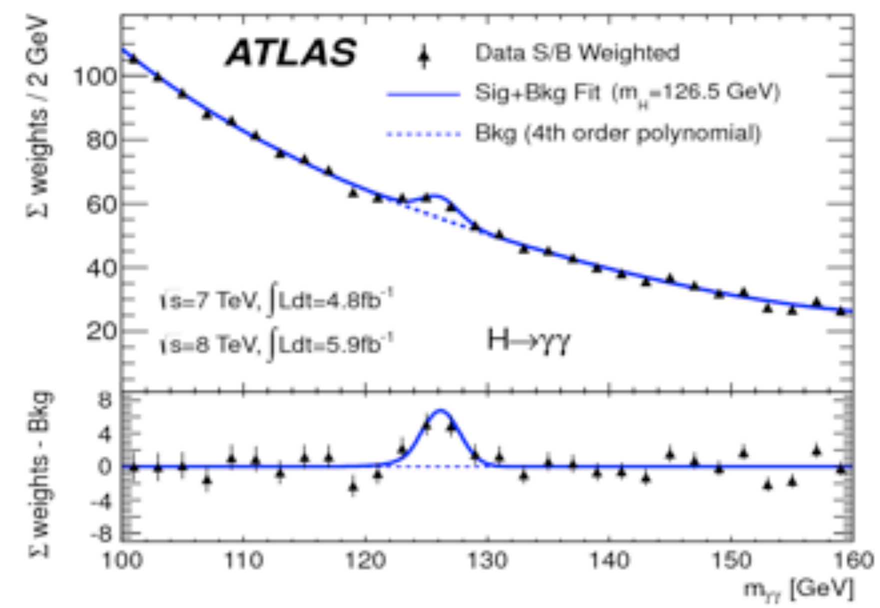
		m_H = 125 GeV
Decay	BR [%]	Unc. [%]
bb	57.7	3.3
ττ	6.32	5.7
cc	2.91	12.2
μμ	0.022	6.0
WW	21.5	4.3
gg	8.57	10.2
ZZ	2.64	4.3
γγ	0.23	5.0
Zγ	0.15	9.0
ΓH [MeV]	4.07	4.0

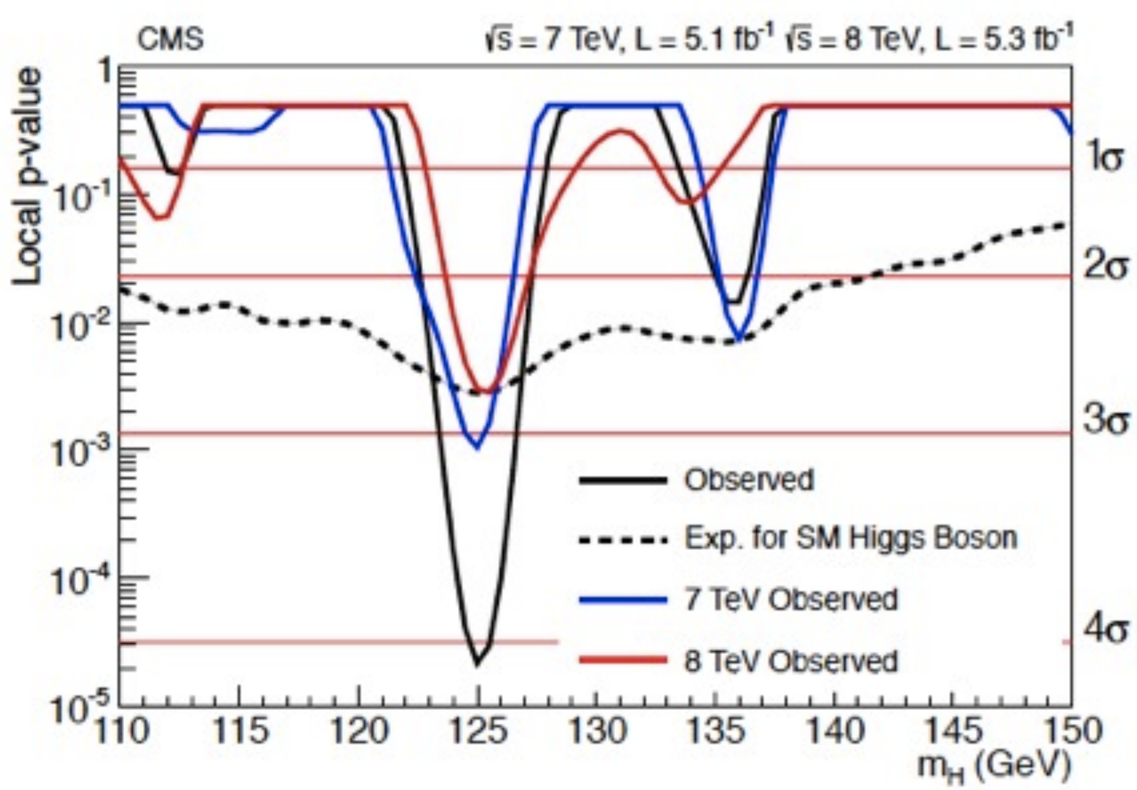
Master table of SM Higgs searches with CMS

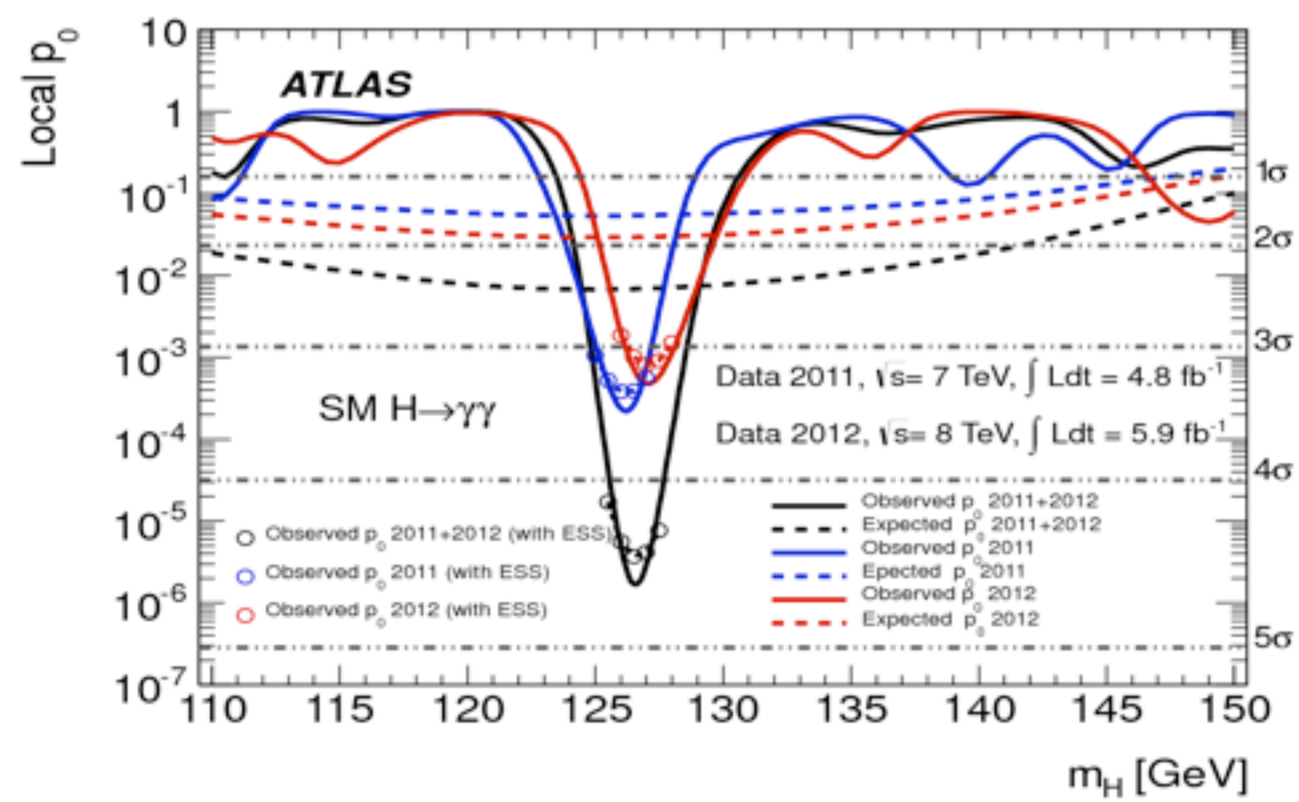
Channel	Mass range [GeV]	Lumi'11 [1/fb]	Lumi'12 [1/fb]	Topologies	gF	VBF	WH &ZH	ttH
H → γγ	110-150	5.1	5.3	incl. + VBF	☺	☺	-	-
H → ττ	110-145	4.9	5.0	0/1 jet + VBF + WH + ZH	☺	☺	☺	-
H → bb	110-135	5.0	5.0	WH + ZH + ttH	-	-	☺	☺
H → ZZ → 4l	110-600	5.1	5.3	inclusive	☺	-	-	-
H → WW → 2l2ν	110-600	4.9	5.3	0/1 jet + VBF + WH + ZH	☺	☺	☺	-
H → ZZ → 2l2ν	200-600	5.0	5.0	0/1 jet + VBF	☺	☺	-	-
H → ZZ → 2l2q	130-600	4.9	-	0/1/2 b-tags	☺	-	-	-
H → WW → lνqq	240-600	4.9	5.1	inclusive	☺	-	-	-

Discovery channel: H → γγ

- **CMS and ATLAS result**
  - Significant excess observed at 125 GeV
  - Consistent between categories
  - Consistent in 7 and 8 TeV data
  - Local significance > 4σ
  - Signal strength > 1

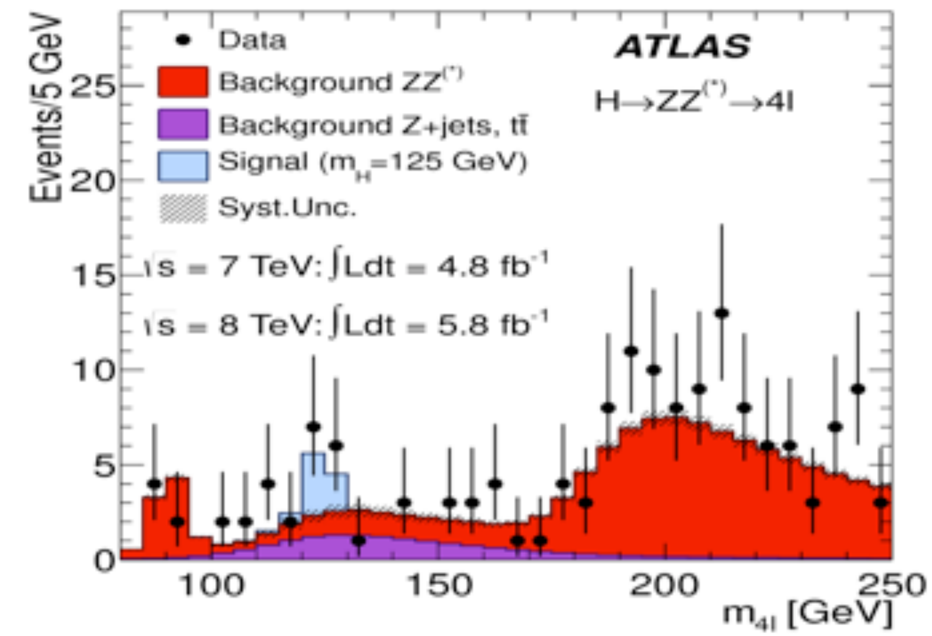


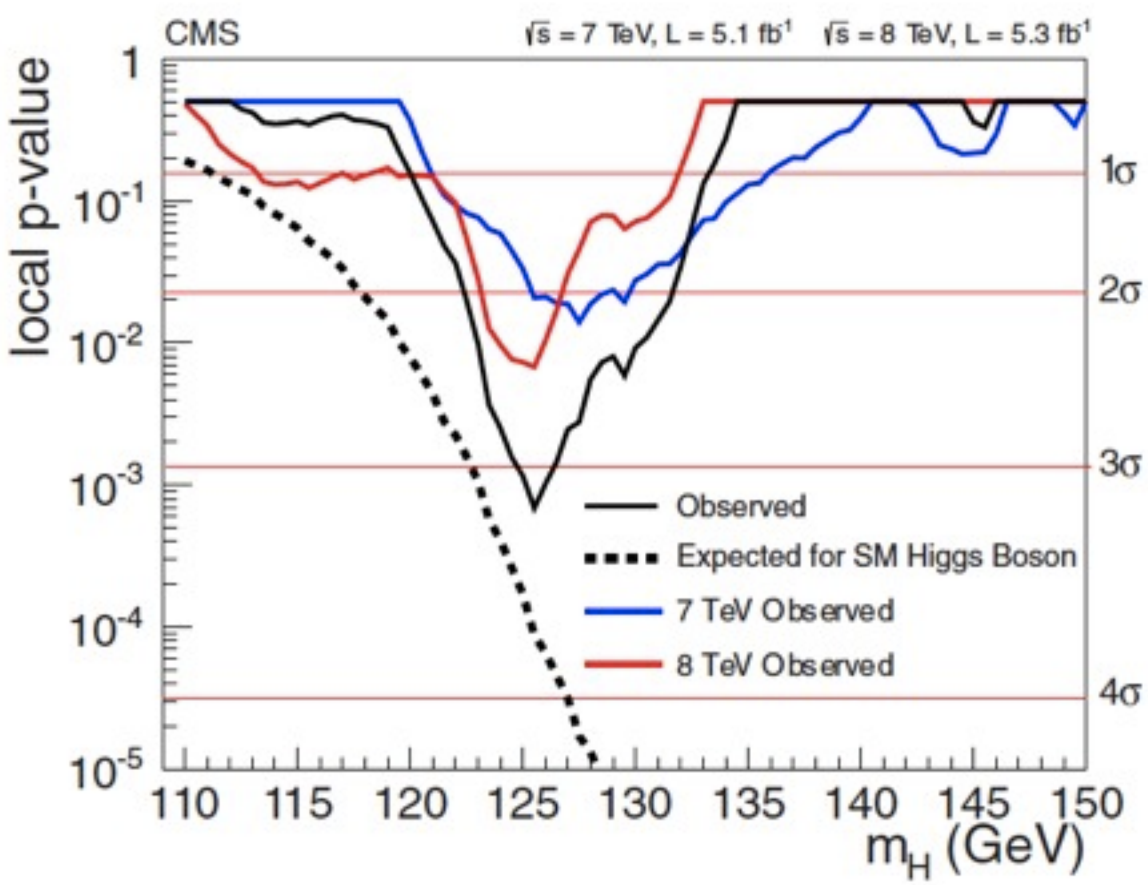


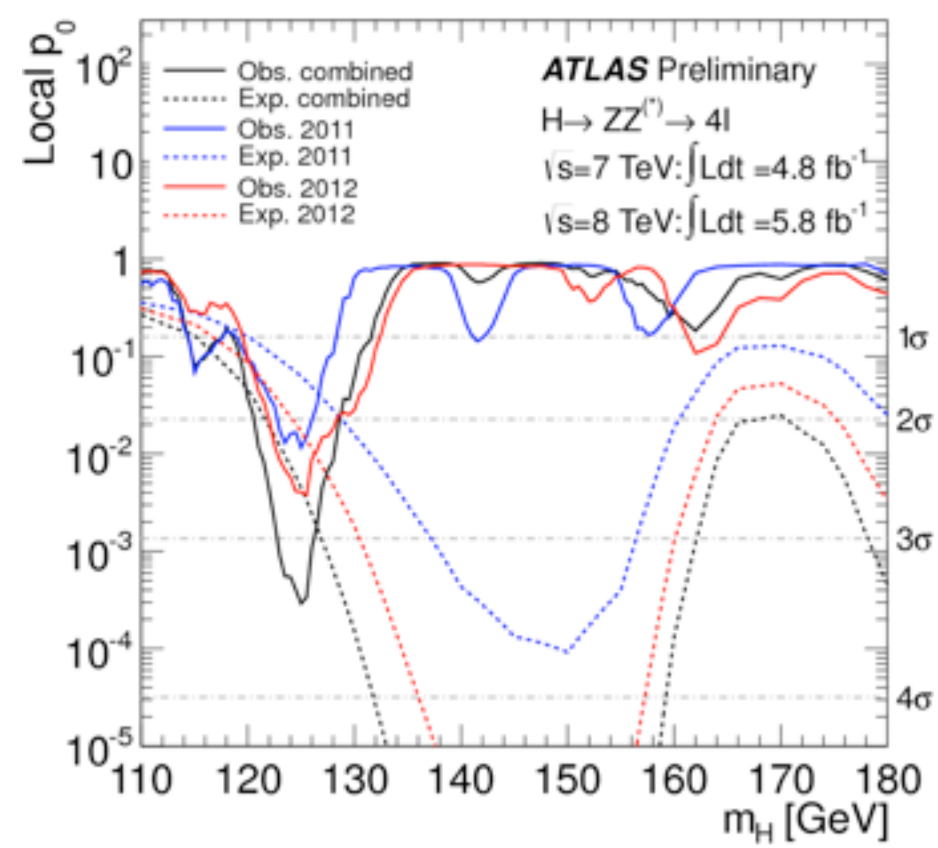


Discovery channel: $H \rightarrow ZZ \rightarrow 4l$

- CMS and ATLAS result
- Significant excess observed at 125 GeV
- Consistent between channels
- Consistent in 7 and 8 TeV data
- Local significance > 3σ
- Signal strength > 1 for ATLAS, < 1 for CMS

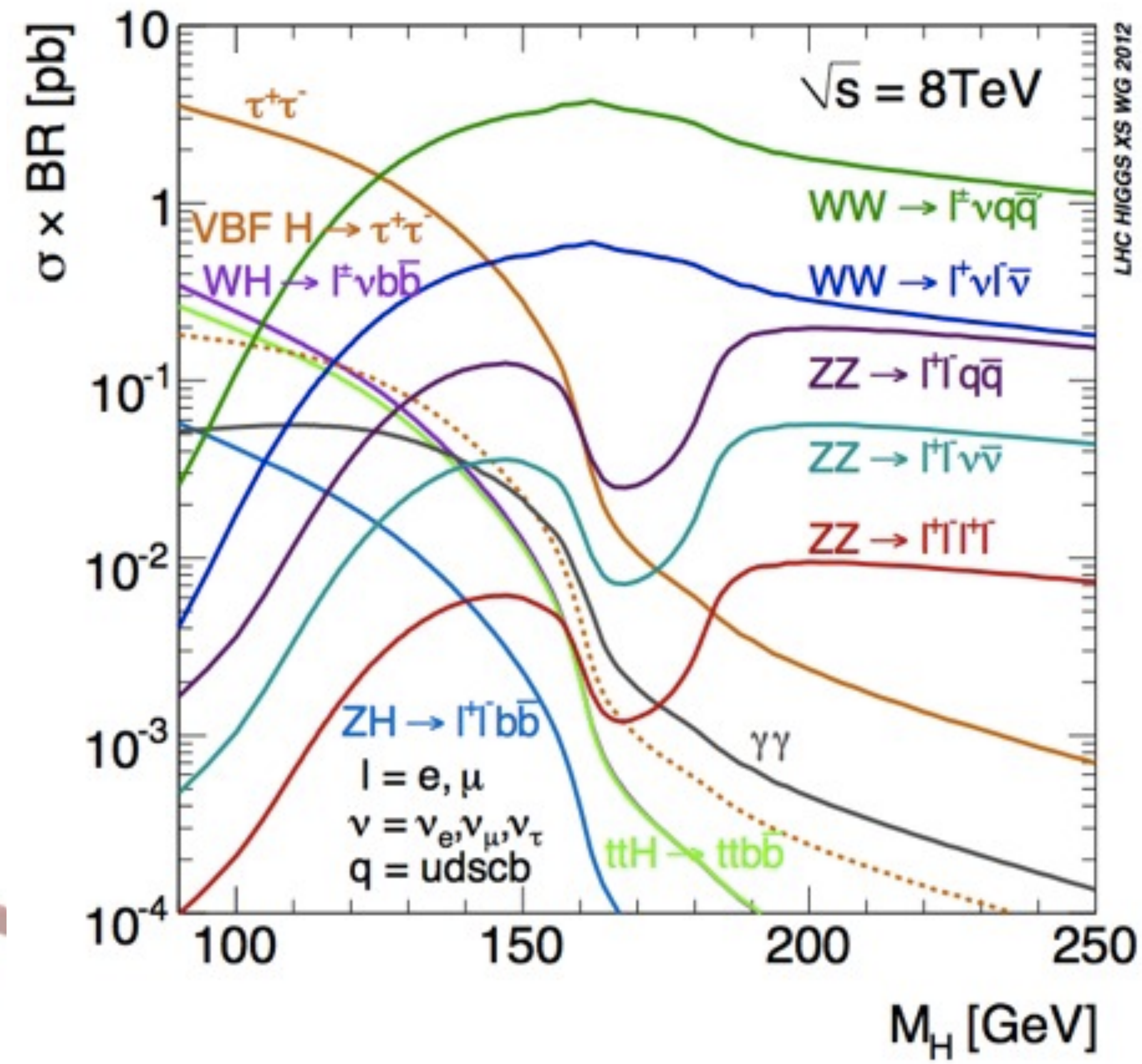






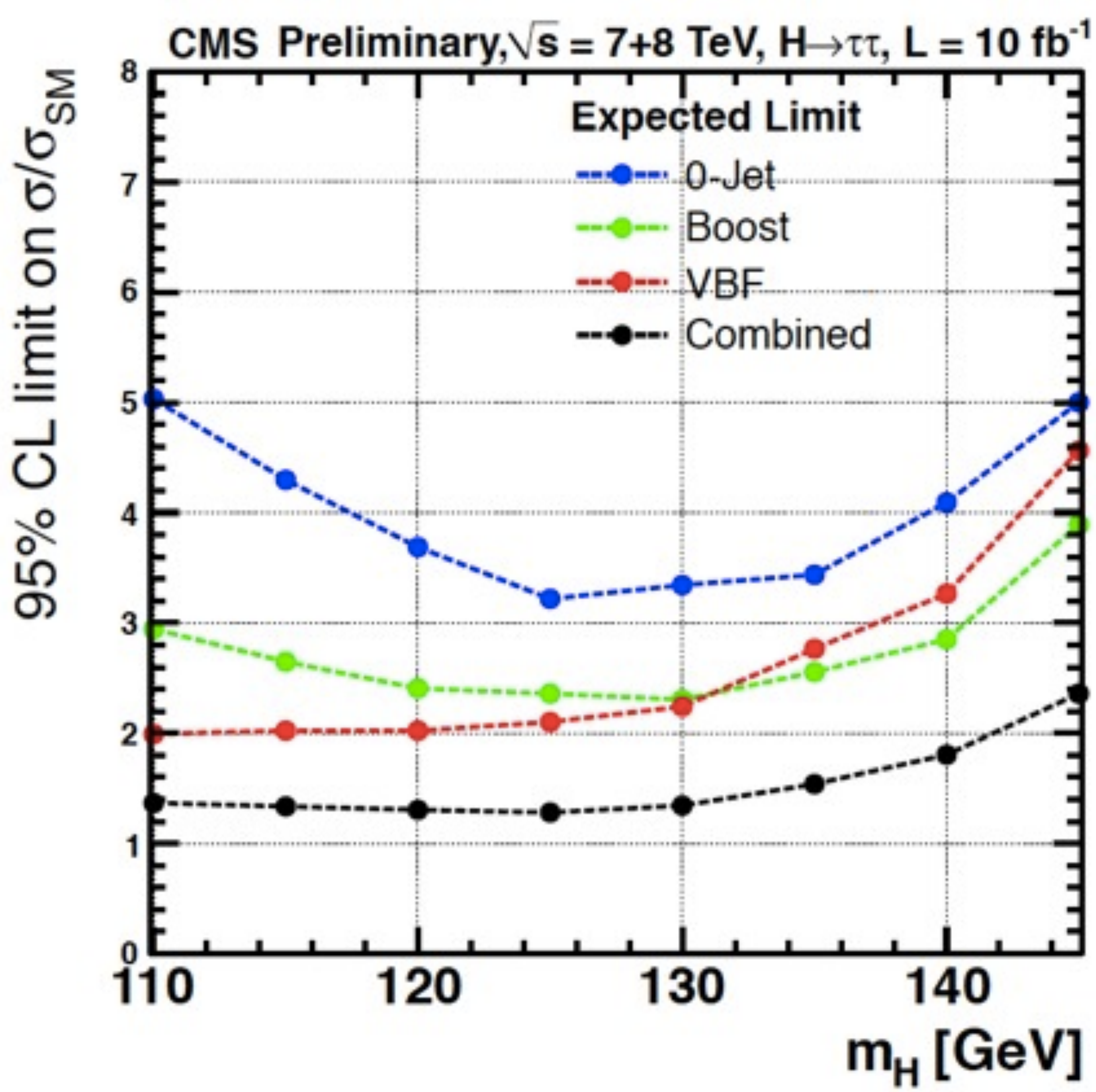
Why is H→ ττ important?

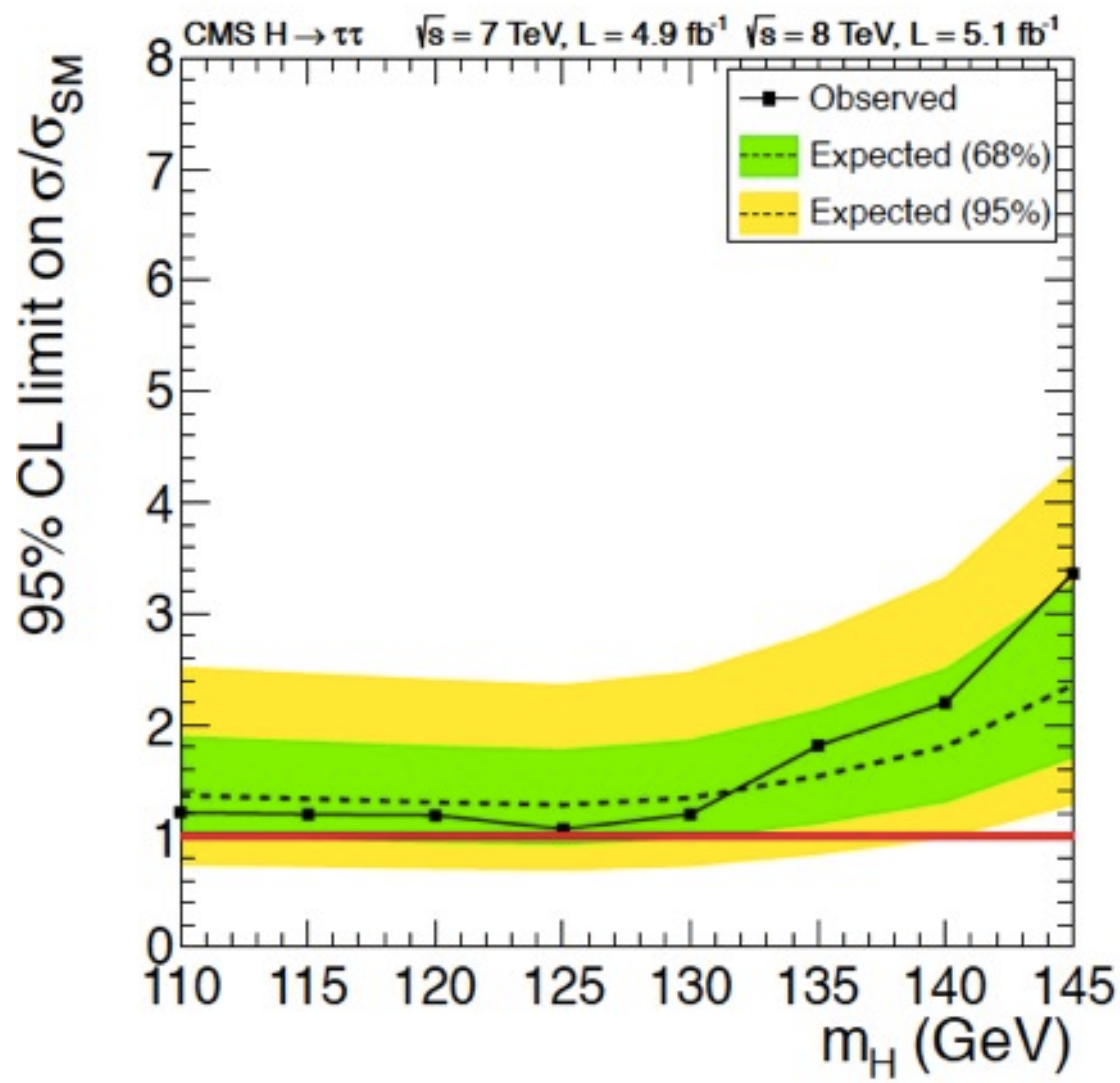
- Highest cross-section x BR
- Only probe of coupling to leptons
- Along with b-quark the only direct probe of coupling to fermions
- Potential to explore properties of new state: CP, spin, couplings
- Great potential to discover or constrain models beyond the SM: 4th fermion generation, supersymmetric models, etc.



Search channel: H → ττ

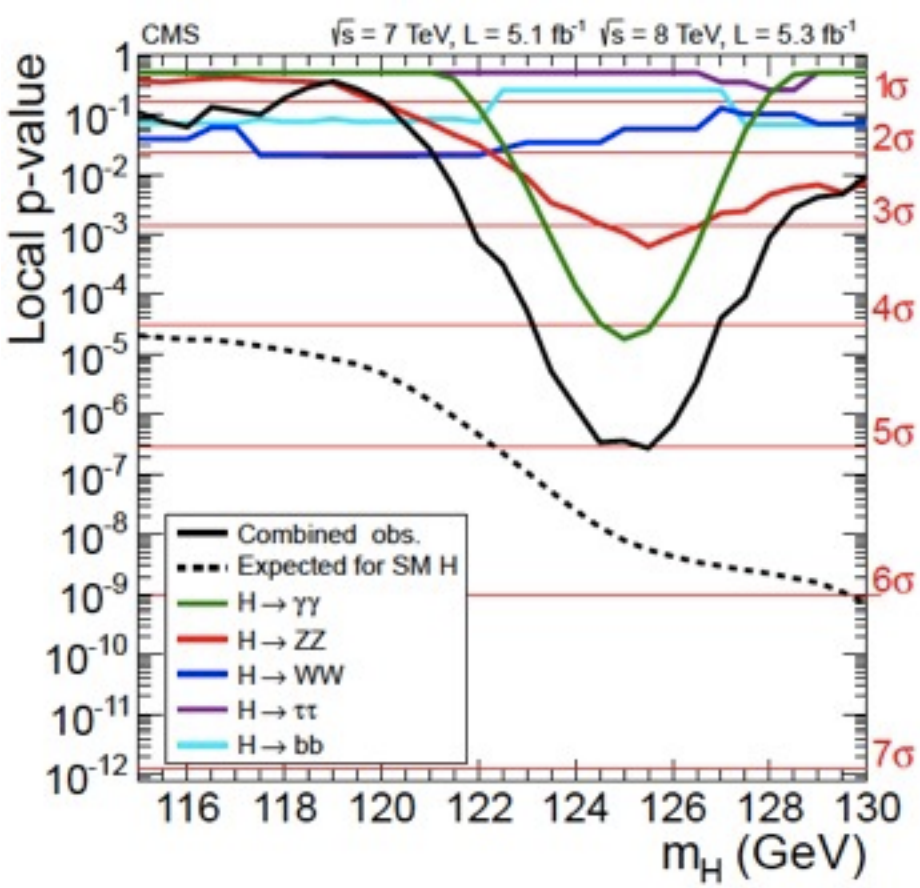
- No excess observed
- Channel compatible with background only or signal
- Sensitivity close to SM cross section
- Waiting for more data and new ATLAS results

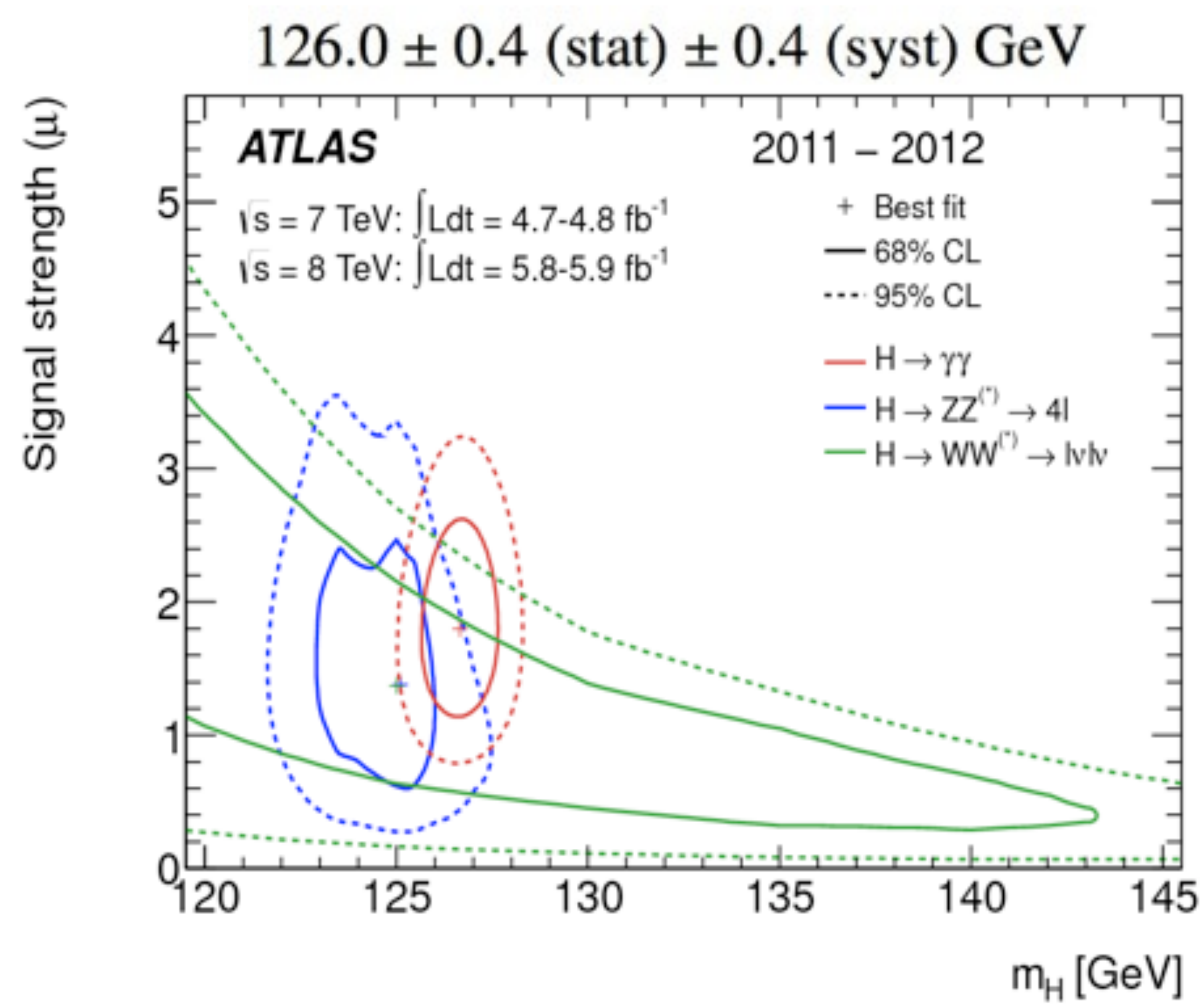




Combination of result

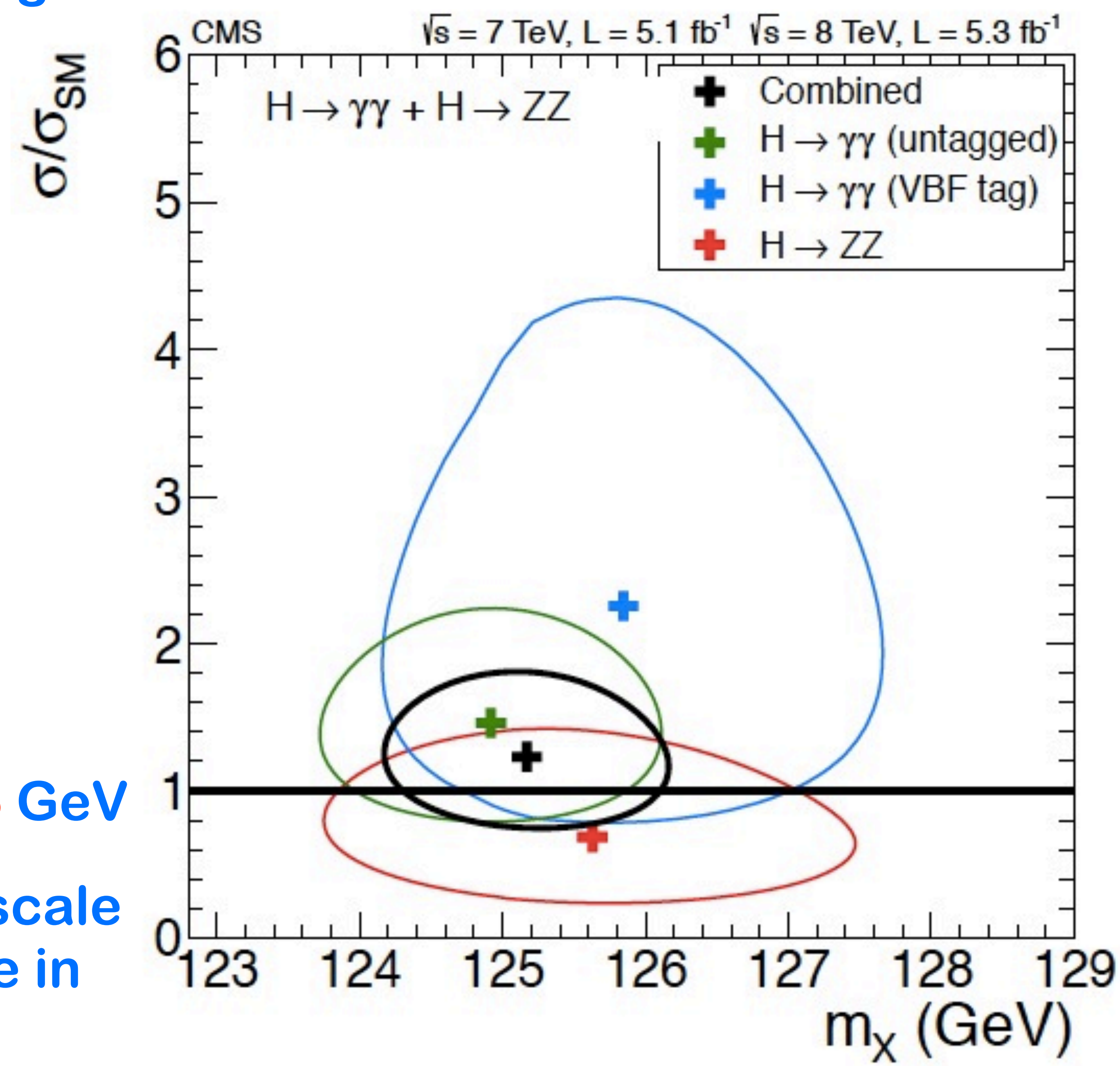
- CMS and ATLAS result
- Significant excess observed at 125 GeV
- Consistent between channels
- Consistent in 7 and 8 TeV data
- Consistent with SM Higgs
- Significance > 5σ



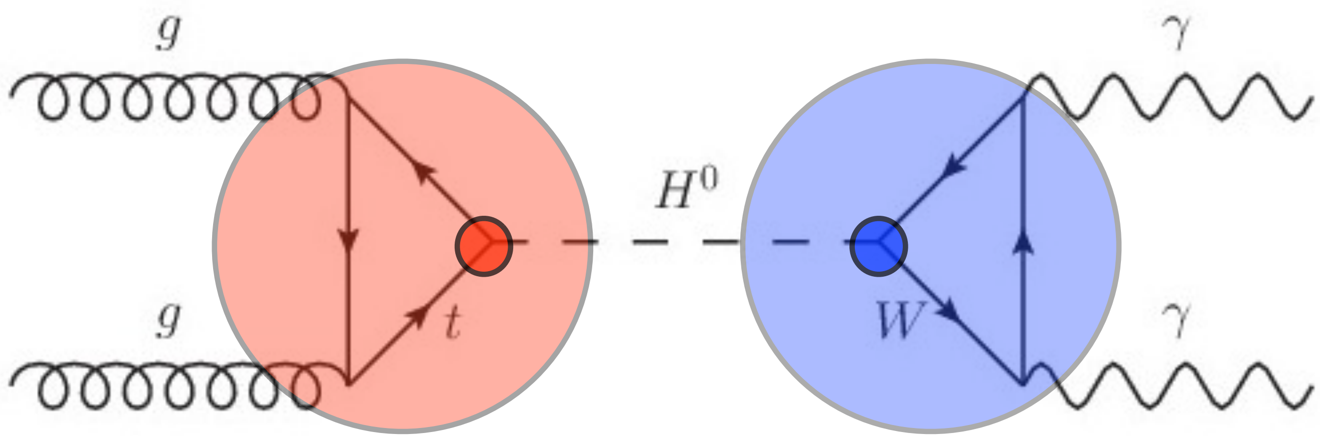


Mass measurement in CMS

- Likelihood scan for mass and signal strength
- Three high mass resolution channels included
  - ZZ → 4l
  - γγ untagged
  - γγ with di-jet tag
- Results are compatible within uncertainties
- Fit of the mass: M = 125.3 ± 0.6 GeV
- Systematics driven by energy scale uncertainty ~0.5%. Will improve in the future.

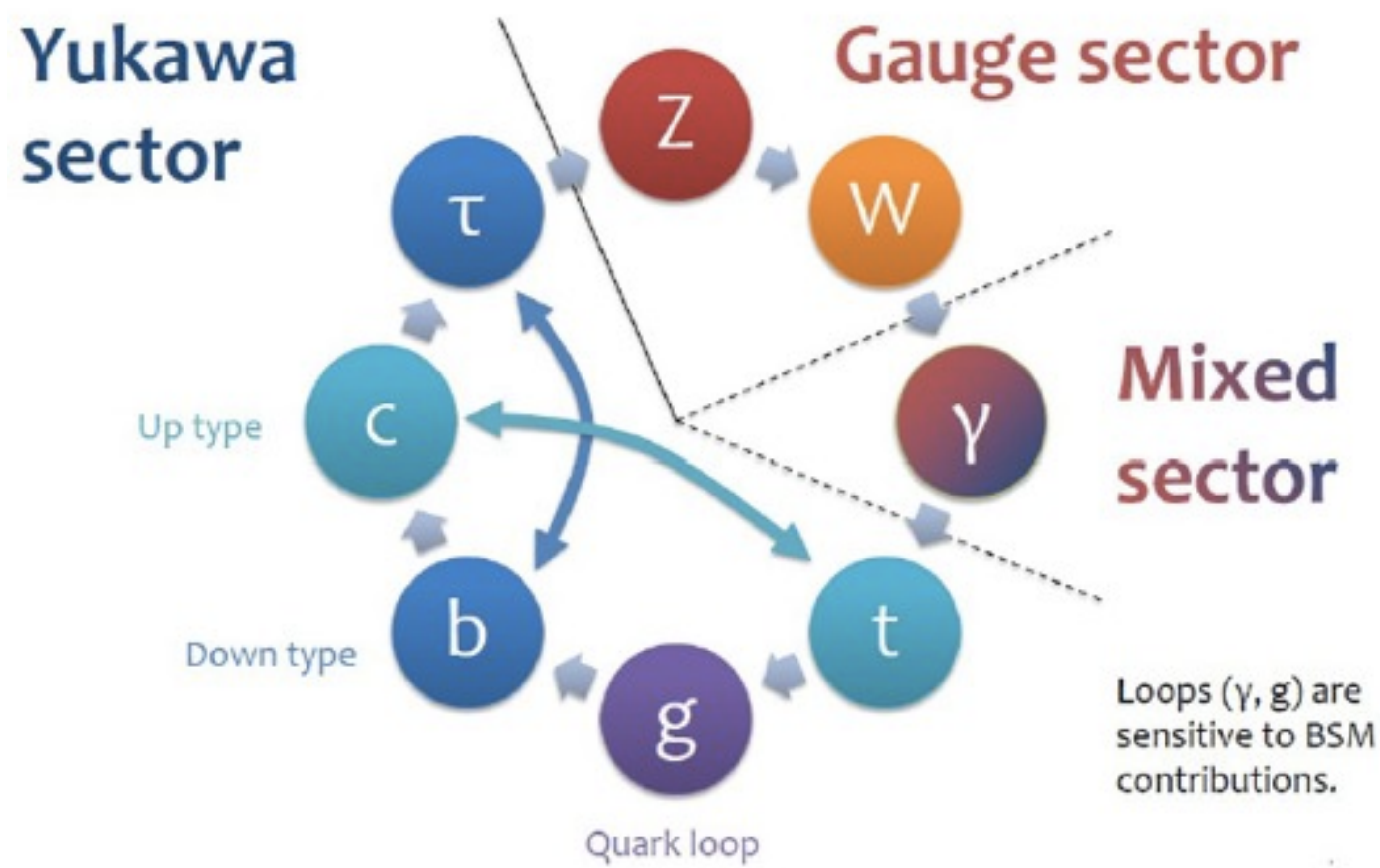


Compatibility with SM Higgs



Each final state tests combination of production and decay and therefore tests two or more Higgs couplings.

Effective theory approach. Fit deviation from the SM expectation. Test varying degree of freedom.



Compatibility with SM Higgs

- Universal coupling fit not available by ATLAS or CMS for now
- Investigated by serval groups combining ATLAS and CMS results
  - arXiv:1205.2699 (accepted by PRL)
    - Lafaye, Plehn, Rauch, Zerwas, Klute
  - update: arXiv:1207.6108 by Plehn and Rauch

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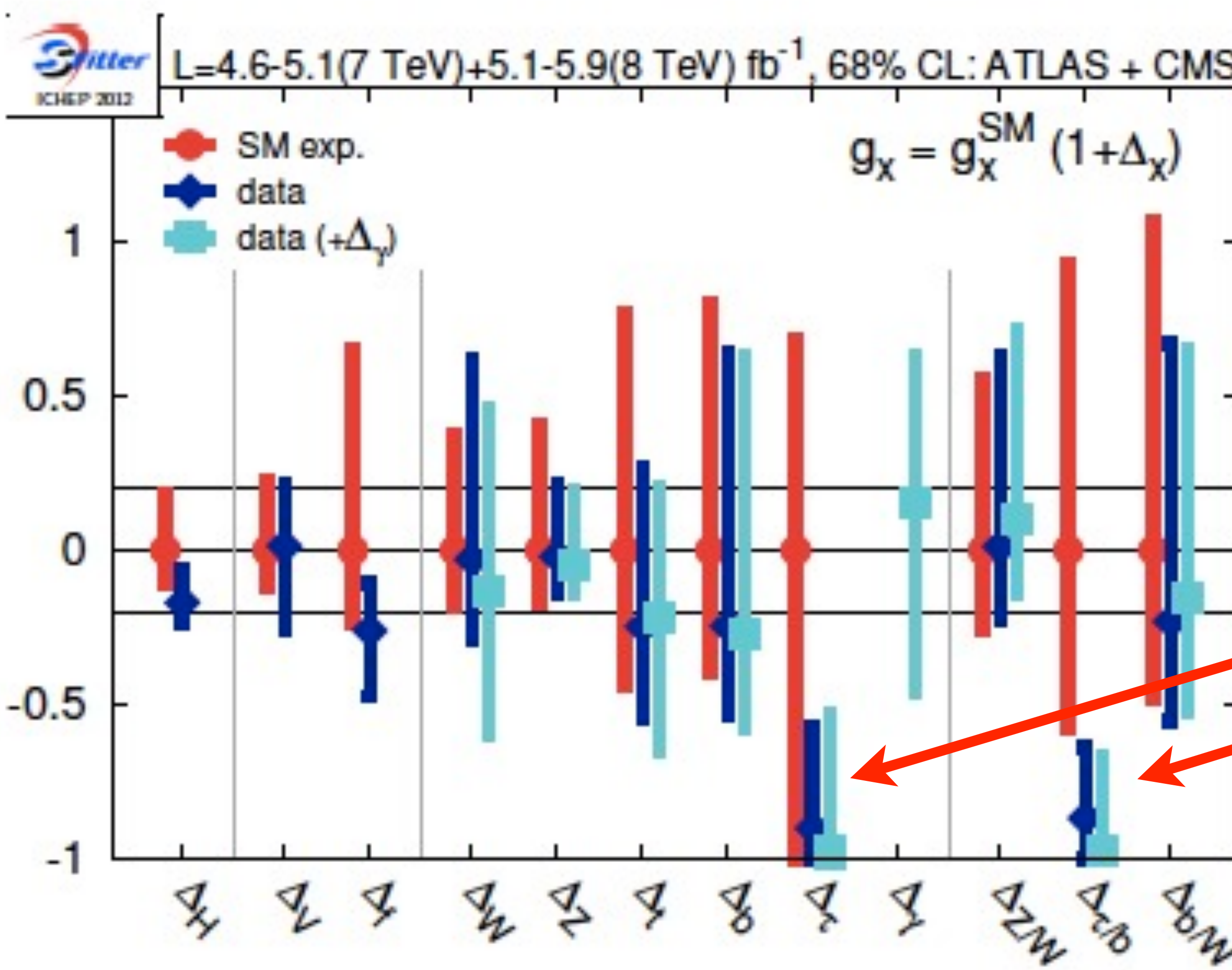
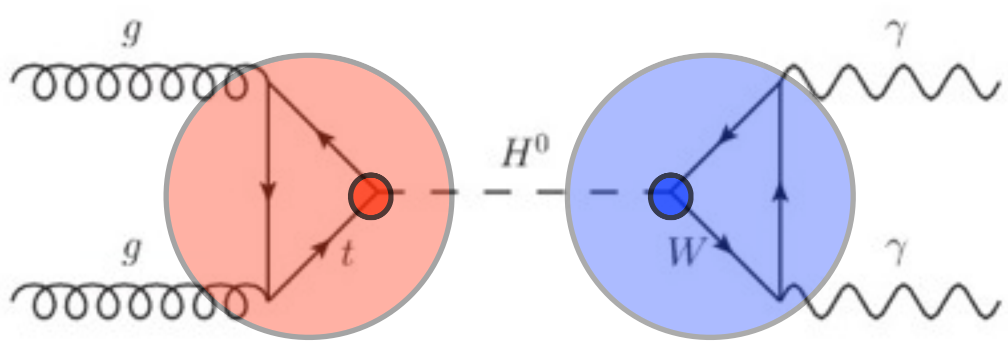


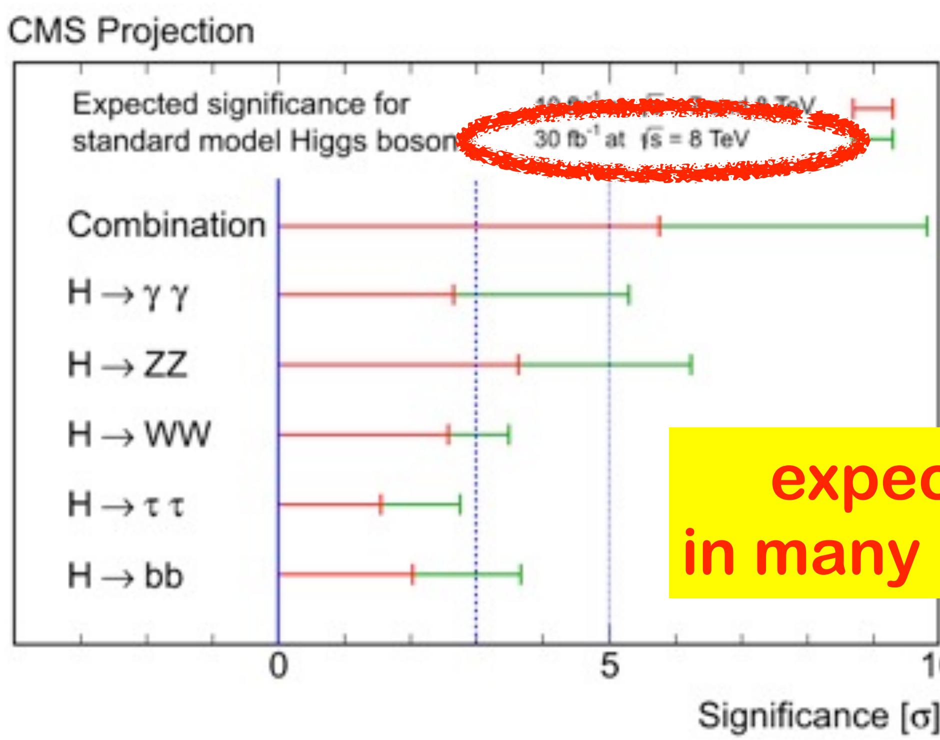
Tension in τ results

What is next at the LHC?

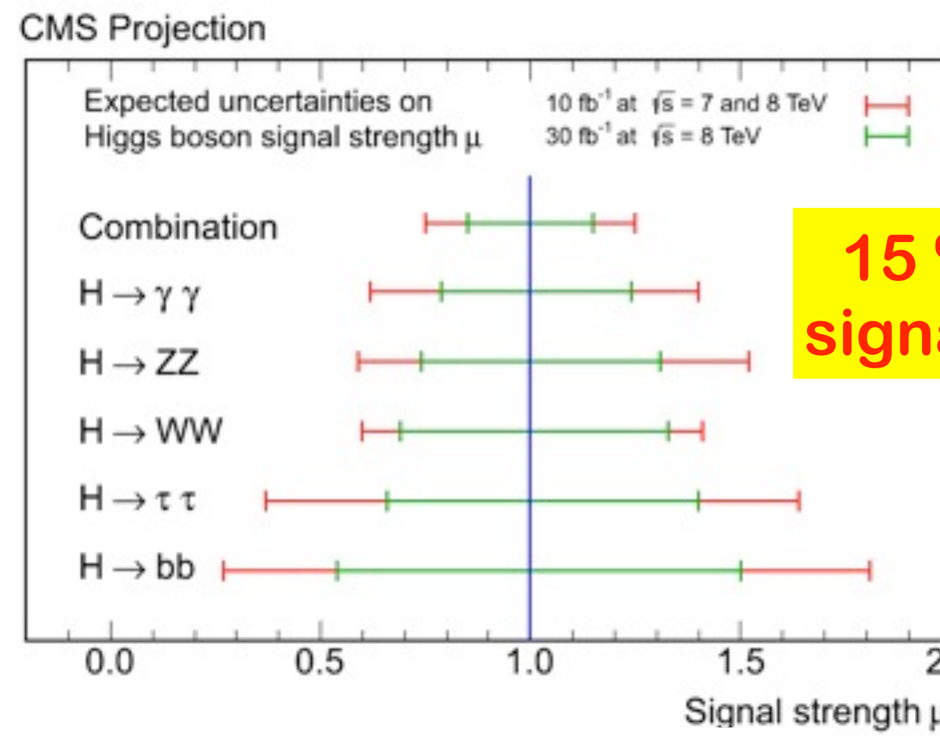
- Continue searches (hope for 30/fb at the end of 2012)
  - cover all possible production and decay channels
  - expand mass range
- Measure properties
  - what is the exact mass
  - measure JCP
    - spin-0 vs spin-2 (spin-1 is already excluded)
    - scalar vs pseudoscalar
  - decompose signal strength in coupling measurements
  - ratio measurements
- Beyond the SM Higgs searches
- Use Higgs as probe for new physics



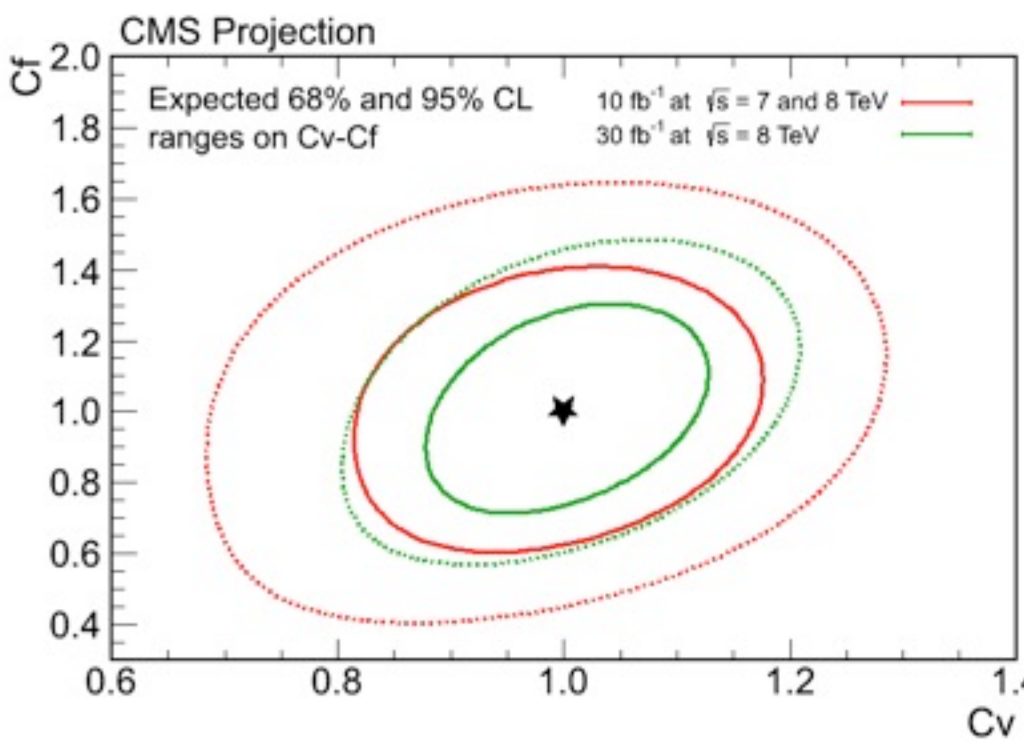
Projecting Higgs Results for 2012

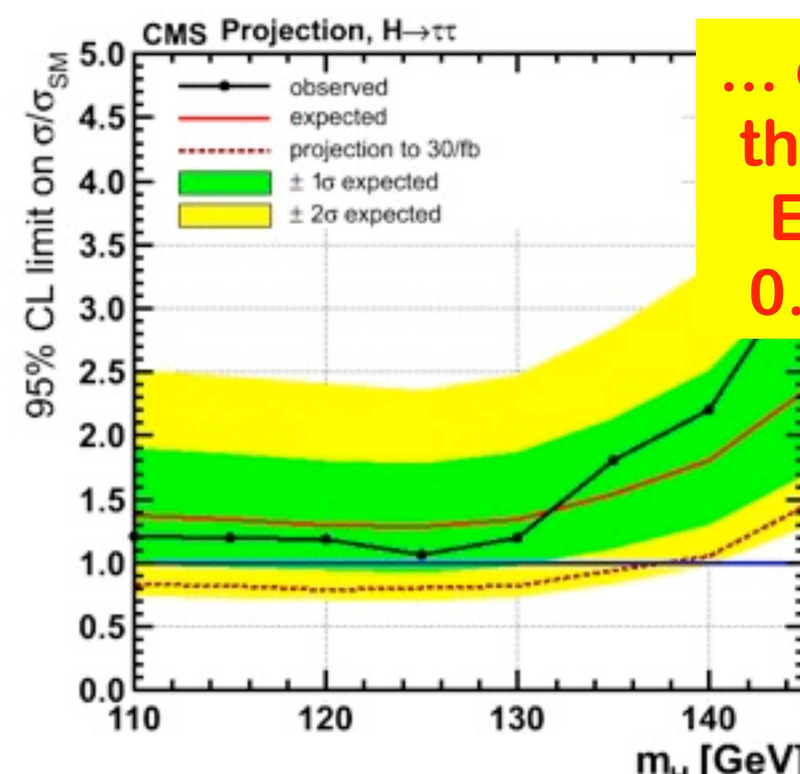


expect > 3σ
in many channels



15 % unc. on
signal strength

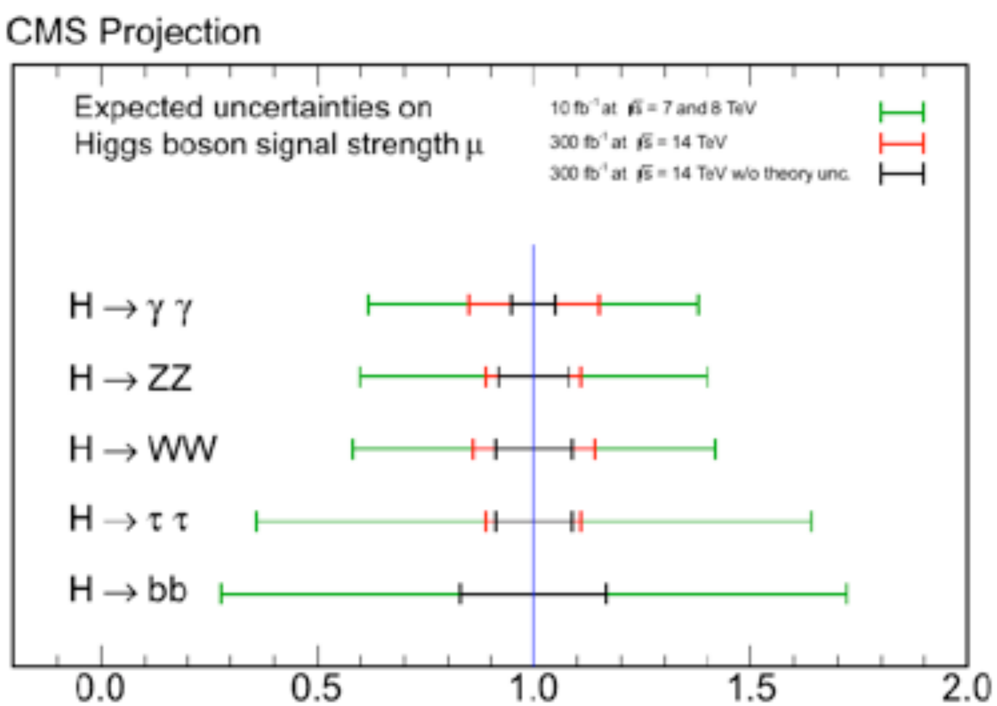


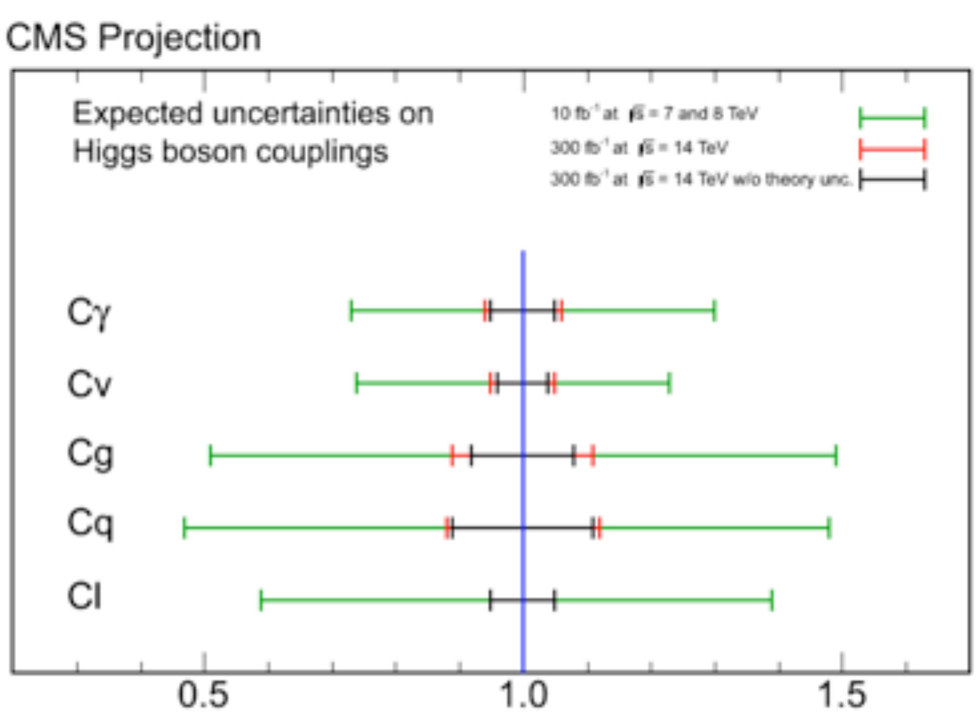


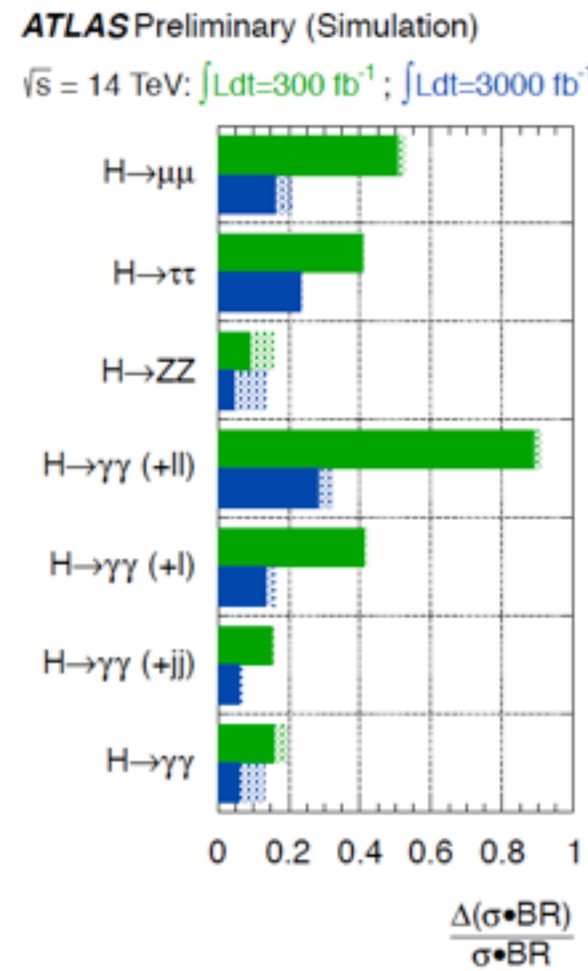
... or we challenge
the SM with taus.
Exp. to exclude
0.85 σ_{SM} 95% CL

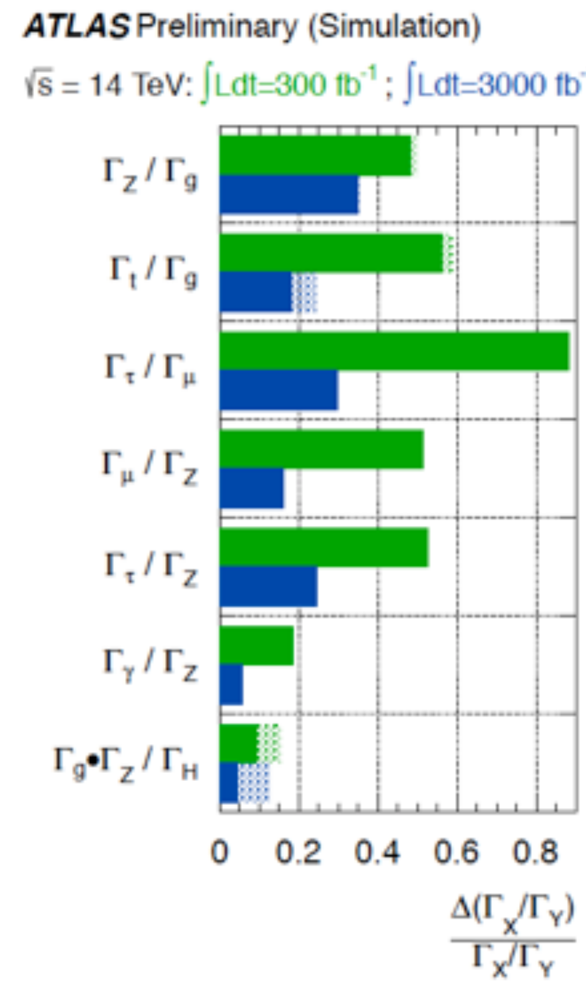
preparing combination with ATLAS in 2013

Projecting Higgs Results for 300fb^{-1} and 3ab^{-1}





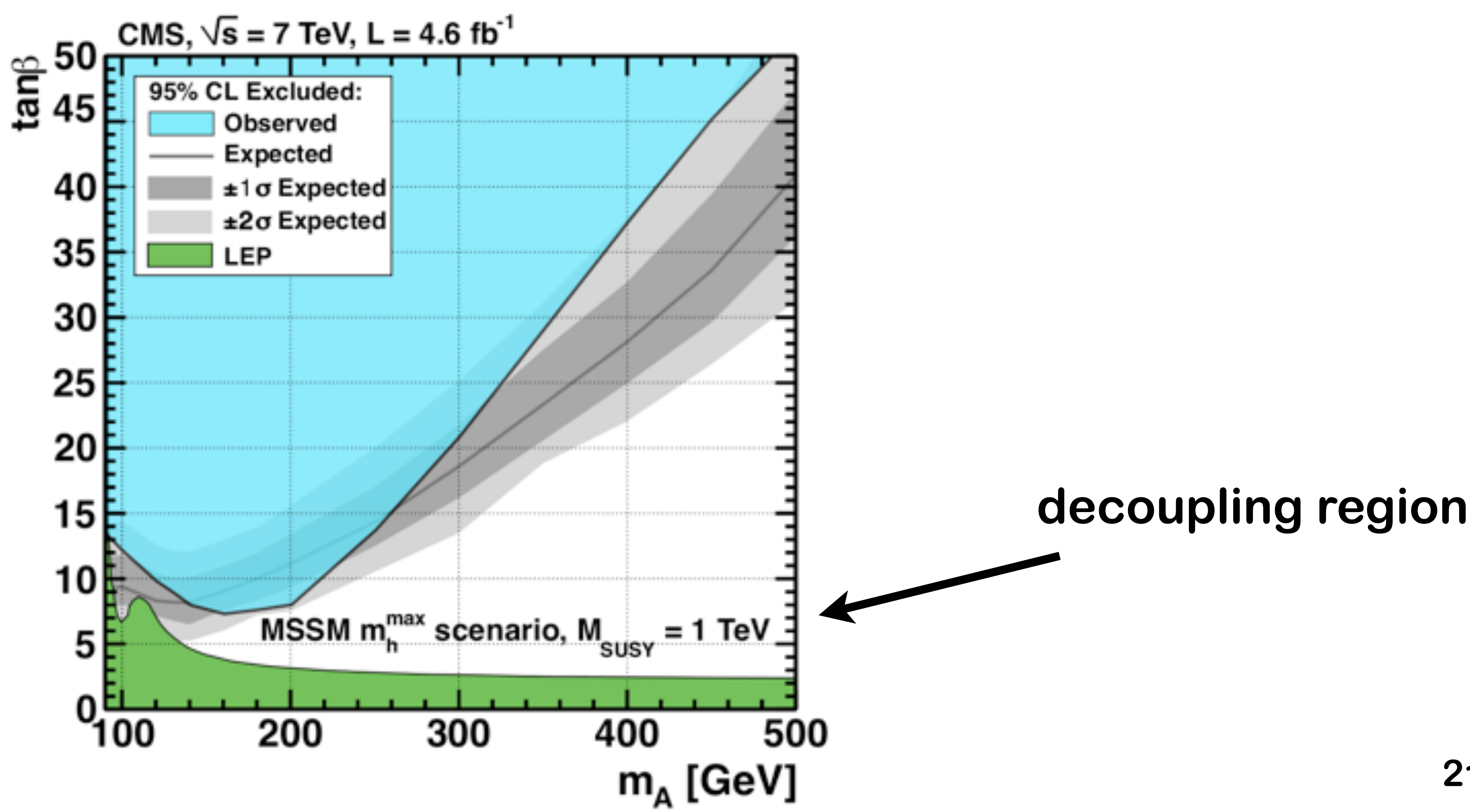




- Projection produced by scaling current Higgs analysis by cross section and luminosity.
- In some cases new studies have been added
- Many caveats need considerations
- Uncertainties on couplings 5-15%

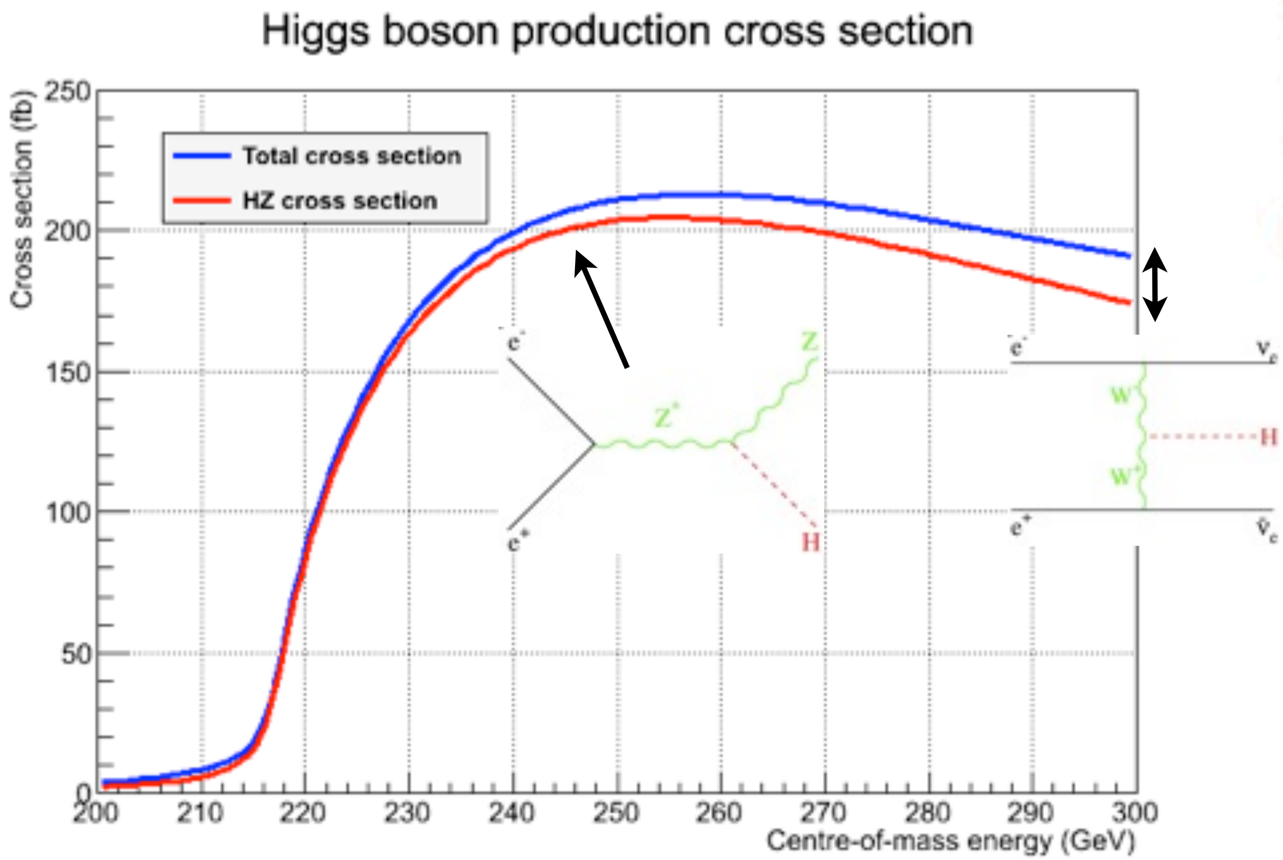
How well do we need to measure the Higgs boson couplings?

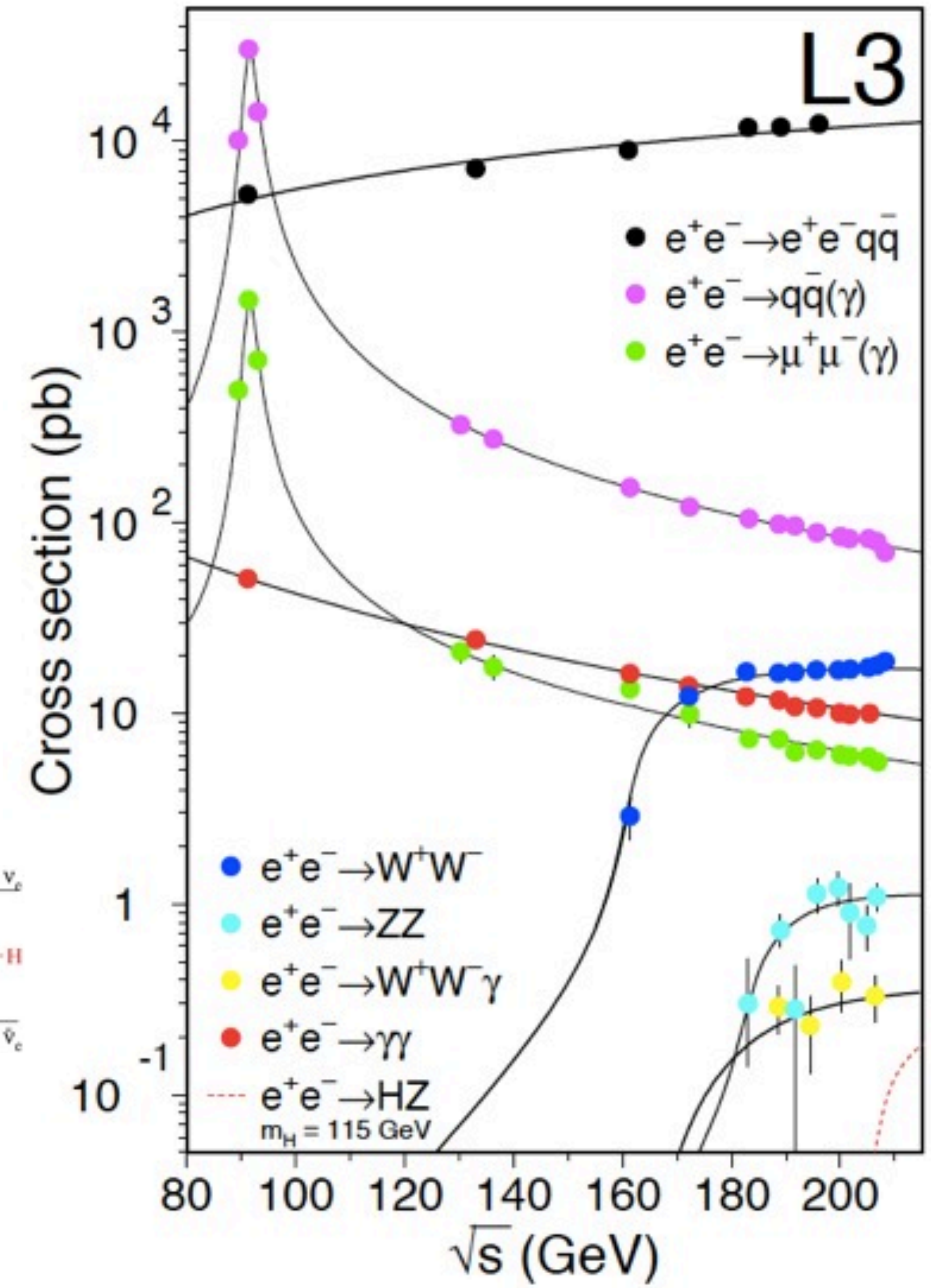
- … discussed by Gupta, Rzehak and Wells in arXiv:1206.3560
- Conclusion, “variations from less than 1% to 100% are possible”
- Reminder, even in the MSSM we find decoupling region where the properties of $H_{SM} = h_{MSSM}$ for large values of mA and moderate values of tan beta.
- Note, uncertainties on SM BR are ~3-12% today



Higgs couplings at e^+e^- collider

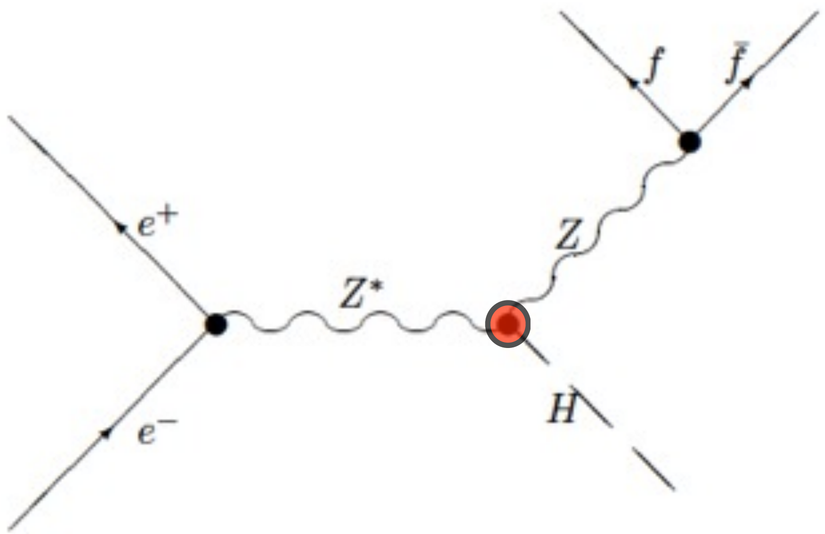
- **Higgs-strahlung is main production process**
  - HZZ coupling observed at the LHC
  - Vector boson fusion give small contribution
- **Cross section plateau at 240-280 GeV**
- **Reasonable background level**



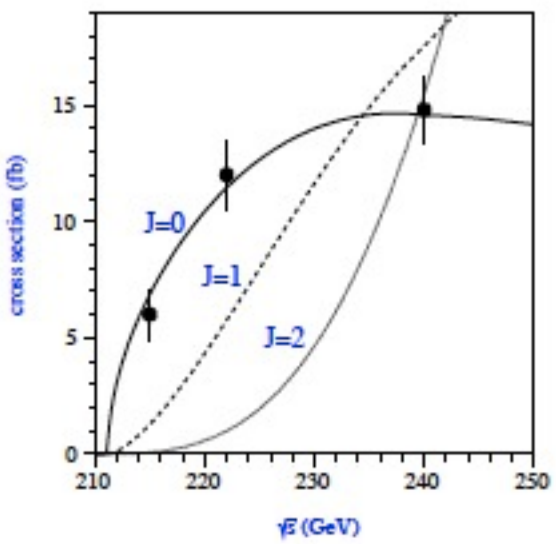


Higgs couplings at e^+e^- collider

- Higgs-strahlung with $Z \rightarrow ll$ allows decay mode independent measurement
  - performed on OPAL data (Eur.Phys.J.C27:311-329,2003)
  - benchmark for linear collider studies
  - sensitive invisible Higgs decays
- Coupling
  - model independent extraction of g_{ZZH} from σ_{ZH} in fit to recoil mass spectrum
  - other Higgs couplings extracted from σ_{HZ} x BR measurements and g_{ZZH}
- Mass
  - can also be measure model dependent
- Spin
  - using $\sqrt{s}$ - scan
- CP properties
  - using angular distributions



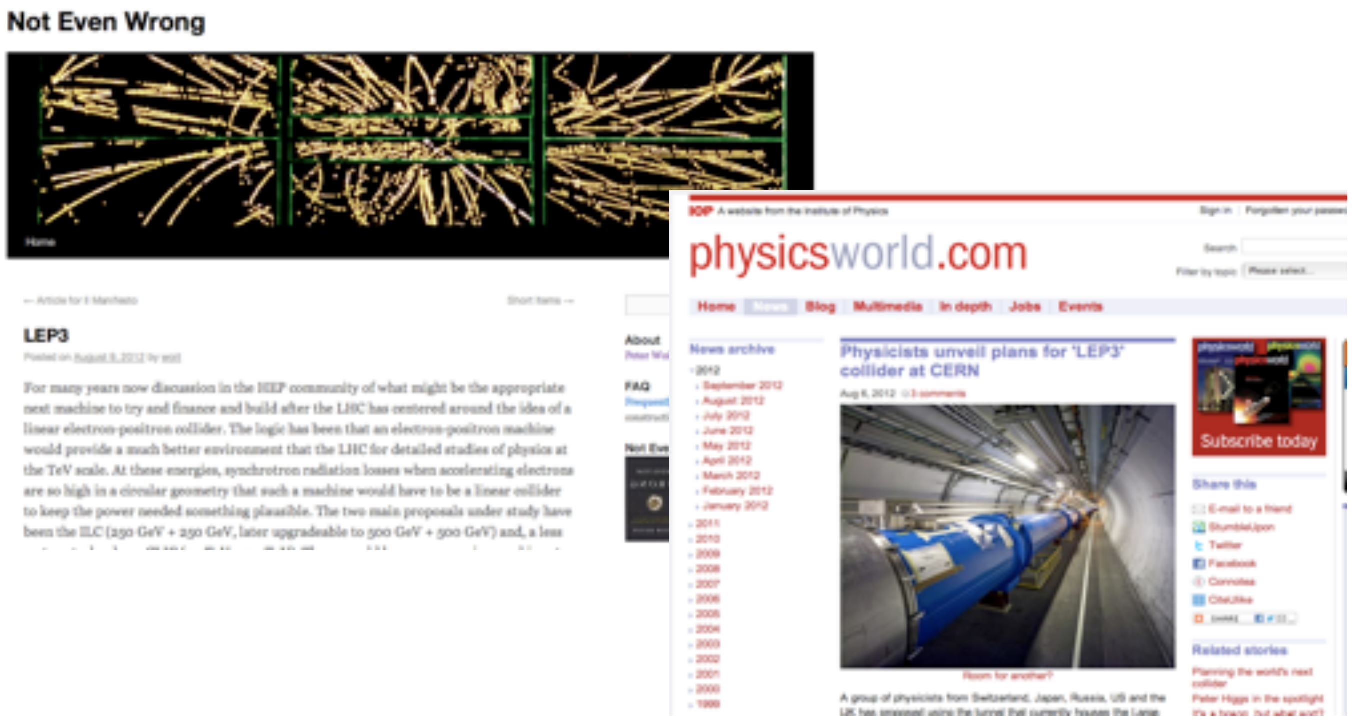
TESLA physics TDR



Circular e^+e^- collider

- $\sqrt{s}$ limited by synchrotron radiation, but
  - 240 GeV not too far from LEP2 (205 GeV)
  - radio frequency cavities can reach much higher gradient today (7 ➜ 30 MV/m)
- Important questions
  - is such a machine possible and what are the limitations?
  - what is the physics potential?
  - what is the prize tag?
- Location and size
  - consider use of 27km LEP/LHC tunnel (LEP3)
  - or a new tunnel at CERN (TLEP) or elsewhere (SuperTRISTAN, FermiLEP, ...)

LEP3 bibliography



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- Prospective Studies for LEP3 with the CMS Detector, P. Azzi, C. Bernet, C. Botta, P. Janot, M. Klute, P. Lenzi, L. Malgeri, M. Zanetti, arXiv:1208.1662
- LEP3: A High Luminosity e+e− Collider to study the Higgs Boson. R.W. Assmann, M. Klute, M. Zanetti et al., arXiv:1208.0504

Synchrotron Radiation, wall power

- SR goes with γ^4 ➜ energy loss per particle ~2x LEP2 (6 GeV)
  - RF gradient of 20MV/m is standard nowadays
  - RF system total length smaller than LEP2 (818 vs 864 m)
    - Including extra RF to increase momentum acceptance (see later)
  - Cryo power (superconducting cavities) similar that of the LHC
- Limit the wall power to 200 MW, 50% wall-to-beam efficiency, ➜ 50MW per beam
  - CERN consumption during LHC operations is ~200MW
- Limit on the wall power translates into limit on beam current and therefore on luminosity
- E_{beam} [100 GeV]$\approx$(P_{SR}[70MW] ρ^2[km]/N_e[10^{12}])$^{0.25}$
  - At E=120 GeV, 4e12 particles per beam
  - Share them among the minimum amount of bunches
    - Constrained by beam-strahlung (see later)

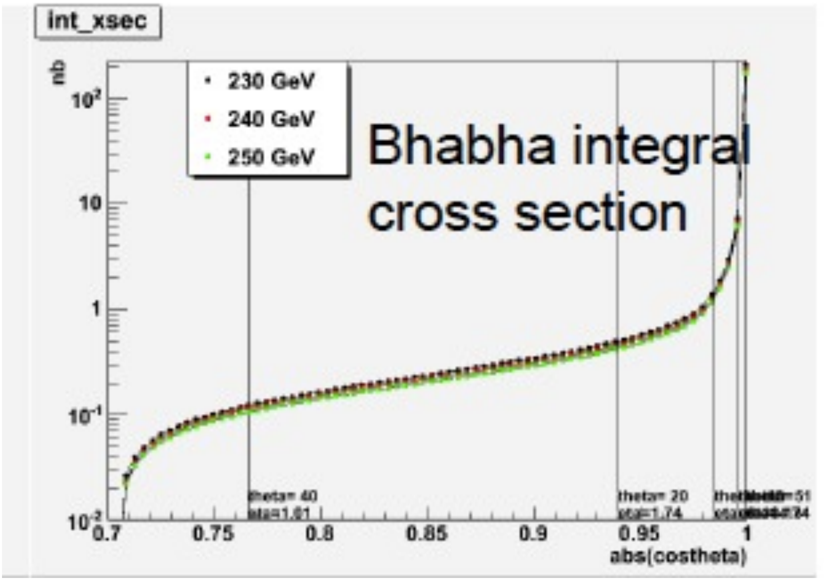
Machine parameters

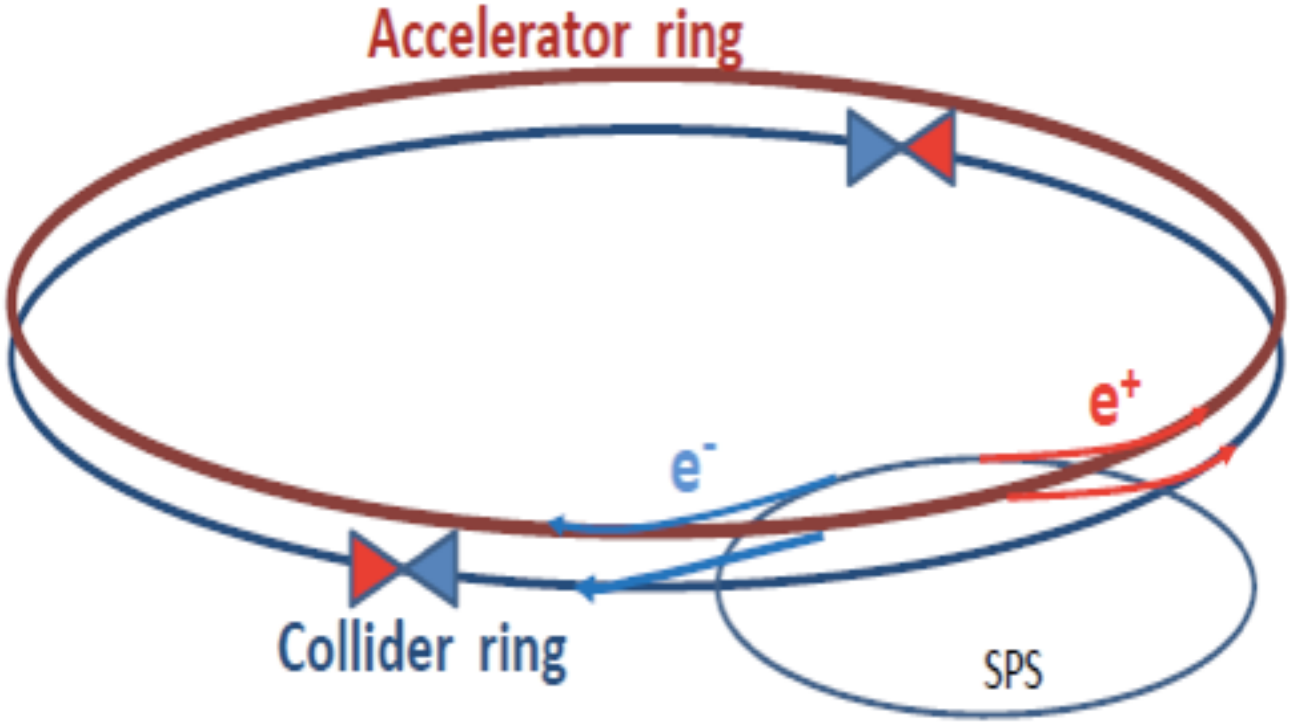
	LEP2	LEP3	TLEP
beam energy E_b [GeV]	104.5	120	175
circumference [km]	26.7	26.7	80
beam current [mA]	4	7.2	5.4
#bunches/beam	4	4	12
$\#e-$/beam [10^{12}]	2.3	4.0	9.0
horiz. emit. [nm]	48	25	20
vert. emit. [nm]	0.25	0.10	0.1
bending radius [km]	3.1	2.6	9.0
partition number J_ϵ	1.1	1.5	1.0
momentum compaction α_c [10^{-5}]	18.5	8.1	1.0
SR power/beam [MW]	11	50	50
β^*_x [m]	1.5	0.2	0.2
β^*_y [cm]	5	0.1	0.1
σ^*_x [μm]	270	71	63
σ^*_y [μm]	3.5	0.32	0.32
hourglass F_{hg}	0.98	0.67	0.65
E^{SR}_{loss}/turn [GeV]	3.41	6.99	9.3
V_{RF},tot [GV]	3.64	12.0	12.0
$\delta_{max,RF}$ [%]	0.77	4.2	4.9
ξ_x/IP	0.025	0.09	0.05
ξ_y/IP	0.065	0.08	0.05
f_s [kHz]	1.6	3.91	0.43
E_{acc} [MV/m]	7.5	20	20
eff. RF length [m]	485	606	600
f_{RF} [MHz]	352	1300	700
δ^{SR}_{rms} [%]	0.22	0.23	0.22
$\sigma^{SR}_{z,rms}$ [cm]	1.61	0.23	0.25
L/IP[10^{32}cm^{-2}s^{-1}]	1.25	107	65
number of IPs	4	2	2
beam lifetime [min]	360	16	54
Υ_{BS} [10^{-4}]	0.2	10	15
n_γ/collision	0.08	0.60	0.51
ΔE^{BS}/col. [MeV]	0.1	33	61
ΔE^{BS}_{rms}/col. [MeV]	0.3	48	95

- Elliptic beams, same H/V ratio as LEP2
  - Relaxed beam sizes
  - Vertical emittance can be further improved
- RF frequency choice between
  - 700 MHz: robust and technologically established
  - 1.3 GHz: more challenging but allows smaller bunch length and ε^*_V
- Beam-beam tune shift much smaller than what reached at KEKB
- Momentum acceptance at 4% to improve beam-strahlung lifetime
- Parameters for lower energies and TLEP scaled from LEP3

Lifetime

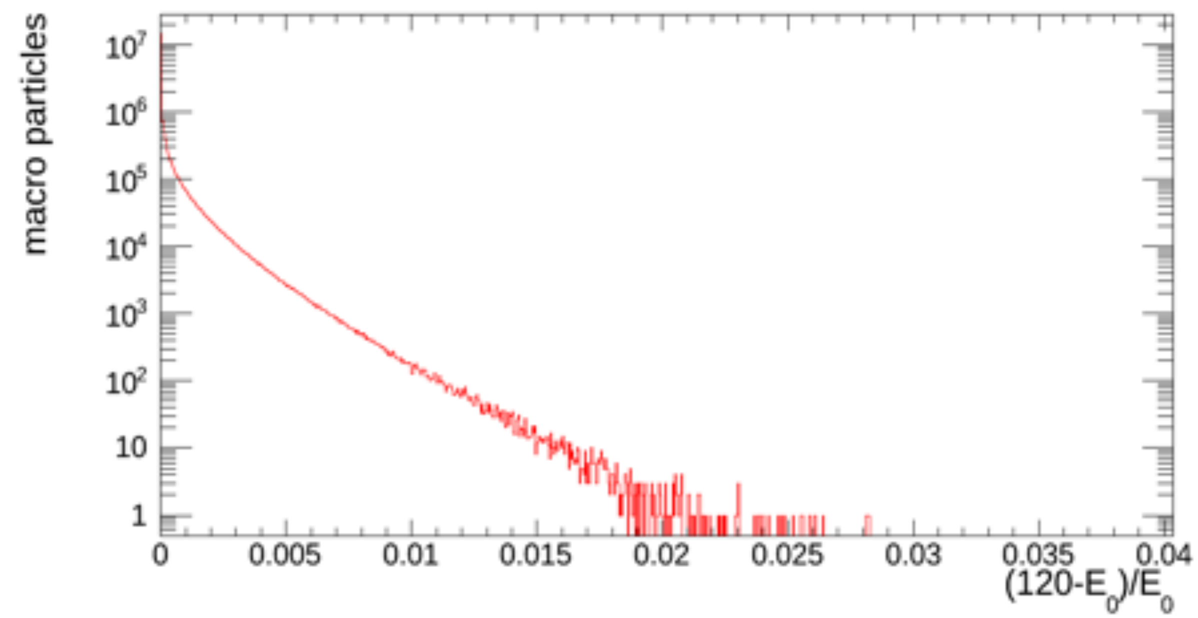
- Already at LEP2 lifetime was dominated by burnoff.
- At L=10^{34} $cm^{-2}s^{-1}$, Bhabha scattering rate so high that burnoff lifetime ~15 minutes.
- Two rings solution
  - Accelerator ring (ramping time <4 min) “topping up” particles to collider ring
    - Increase by ~50MW total wall power
  - 4e12 positrons every 4 min, 2e10 positrons per second (1e11 at LEP2)



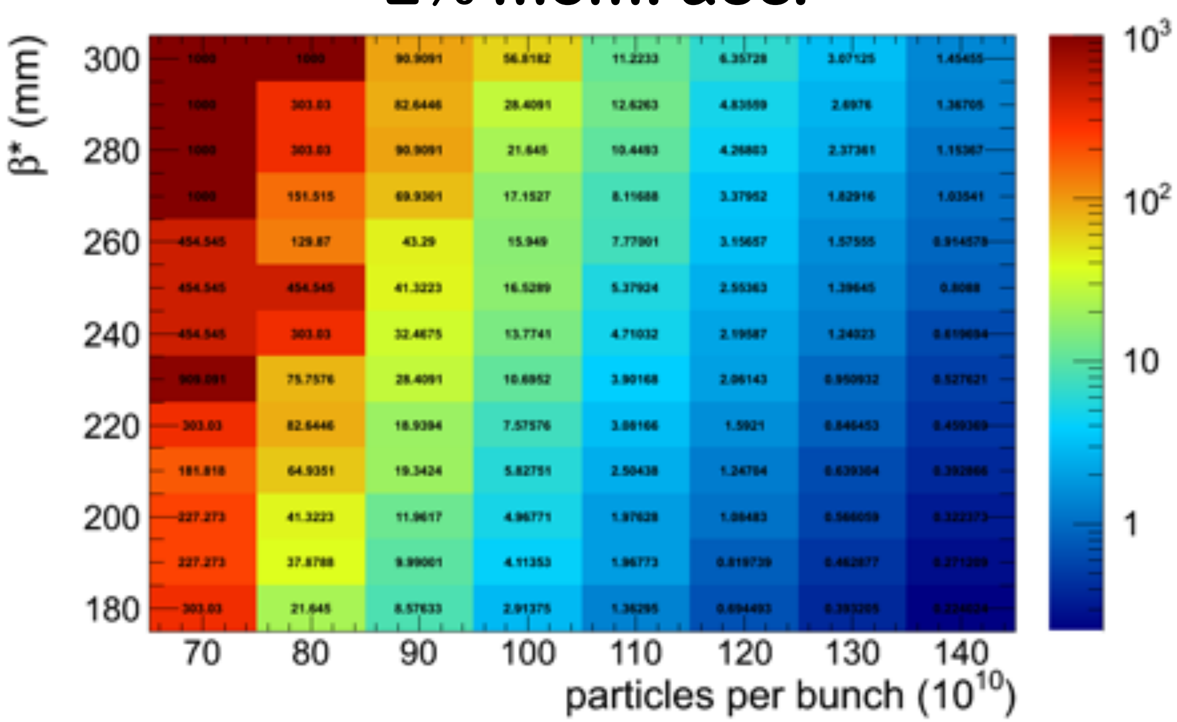


Beam-strahlung

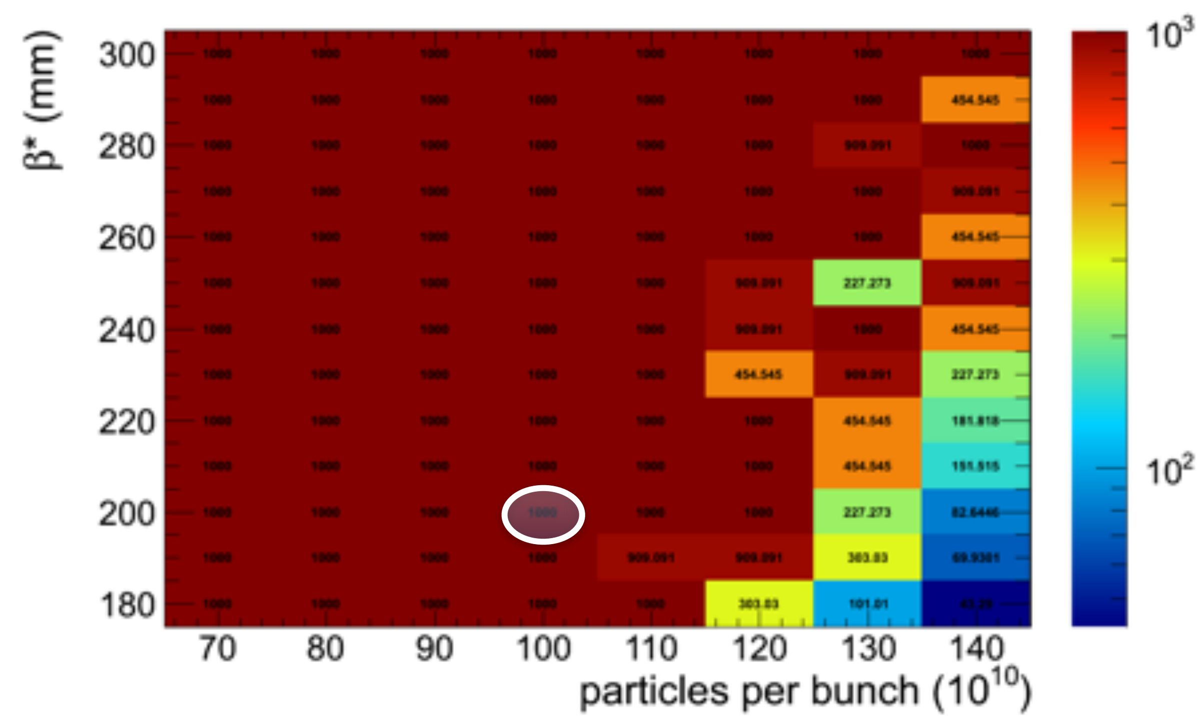
- Believed to be main show-stopper for high lumi e^+e^- circular machine
- Small beams dimensions at IP imply strong EM interactions between particles in the beam causing tails in the energy spread
- The repetition rate (4x11kHz) is such that fraction of particle loss can become very large in short time -> short lifetime
- Increase energy acceptance and adjust beam parameters



2% mom. acc.



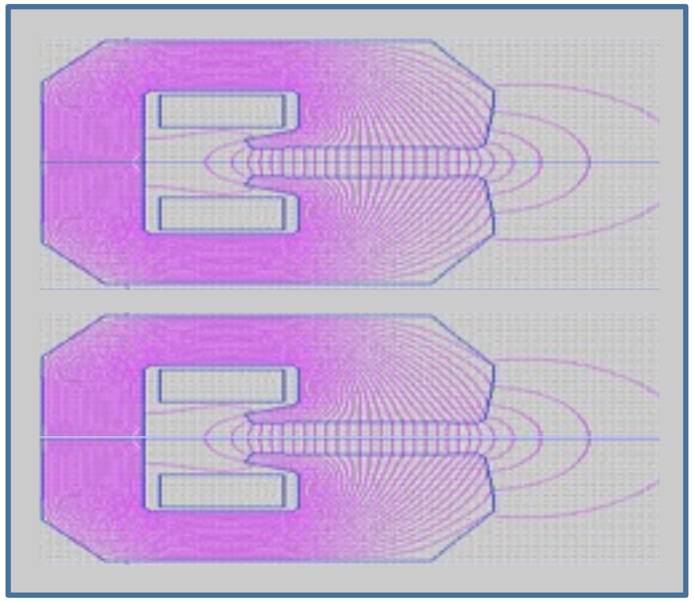
4% mom. acc.



Markus Klute

Dipoles

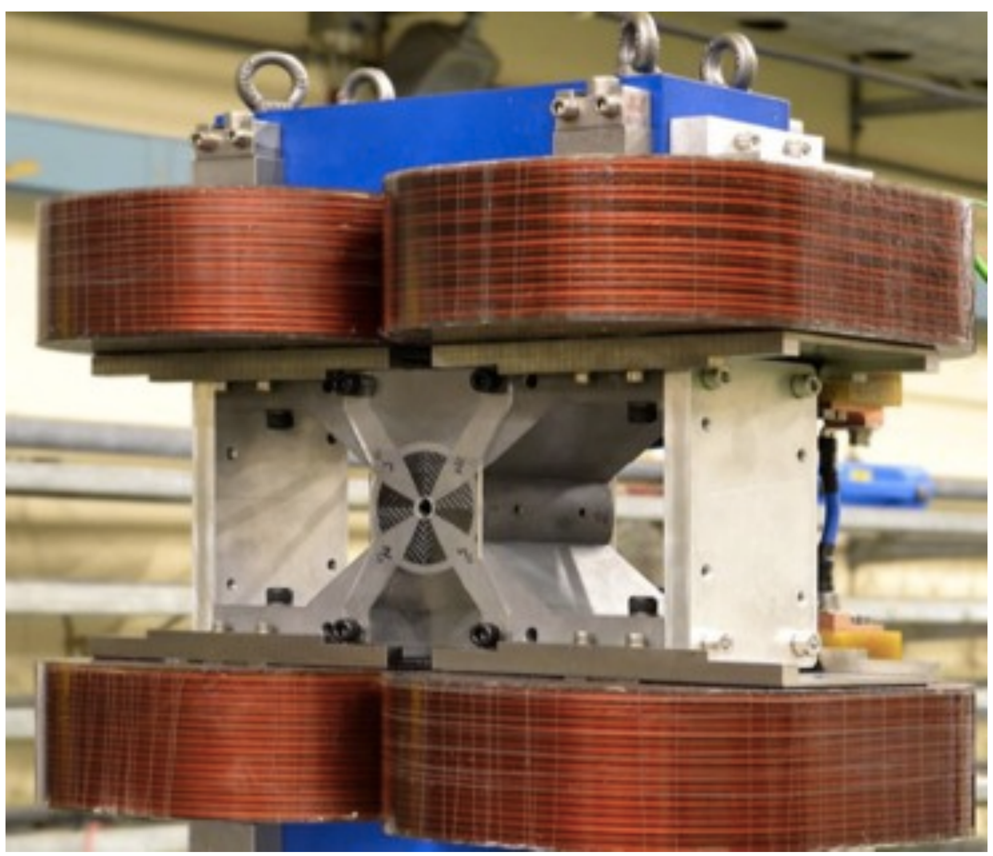
- Compact, light, low field (0.153 T) and low cost magnets
  - For a possible coexistence with LHC
- “Double decker” version of LHeC ones
  - Dynamic alignment can improve the vertical emittance



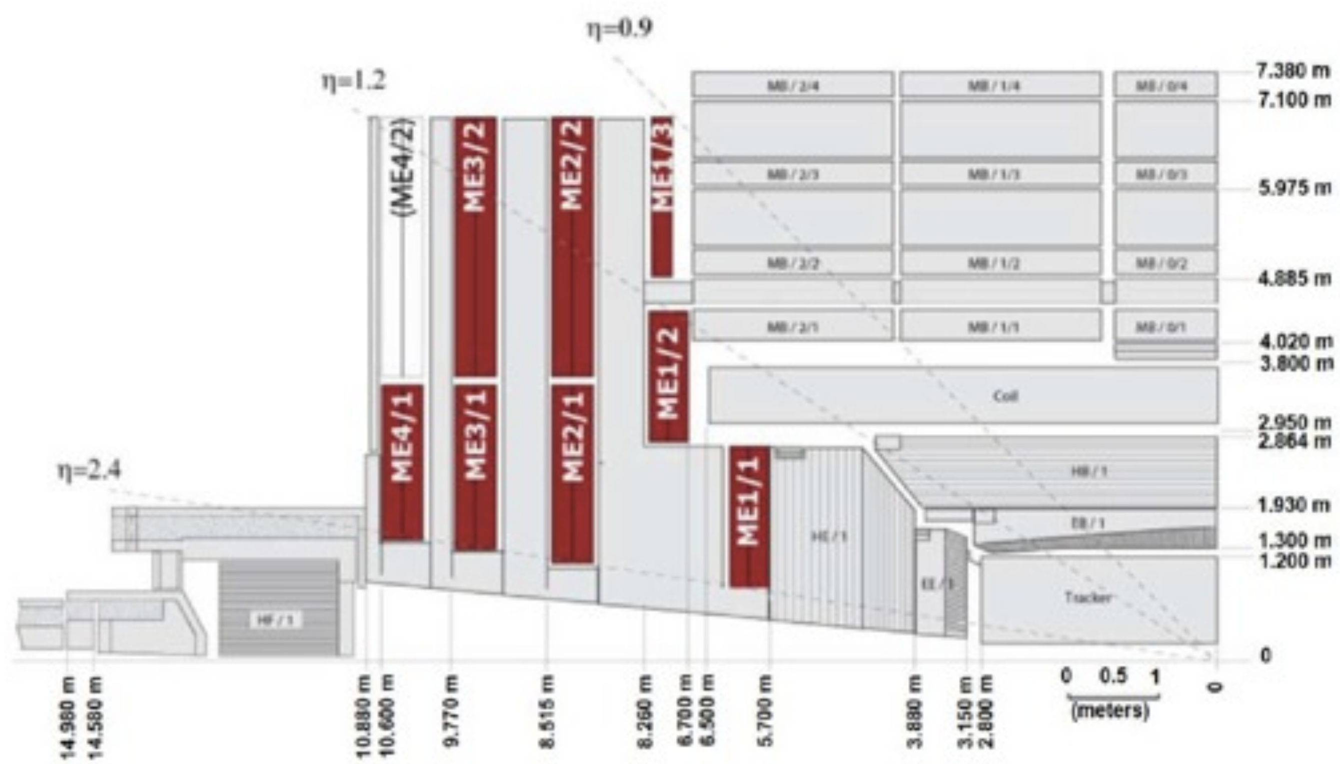
Final focus

- As for the ILC, focusing quadrupoles need to sit very close to the IP(~4m)
- Design β^*_V requires 17 T/m gradient, with an aperture of 5 cm corresponding to ~20 σ
- Very small (r<20 cm) prototype magnets have been produced already
  - SC Nb3Sn (HE-LHC) or hybrid permanent/EM as options

500 T/m CLIC

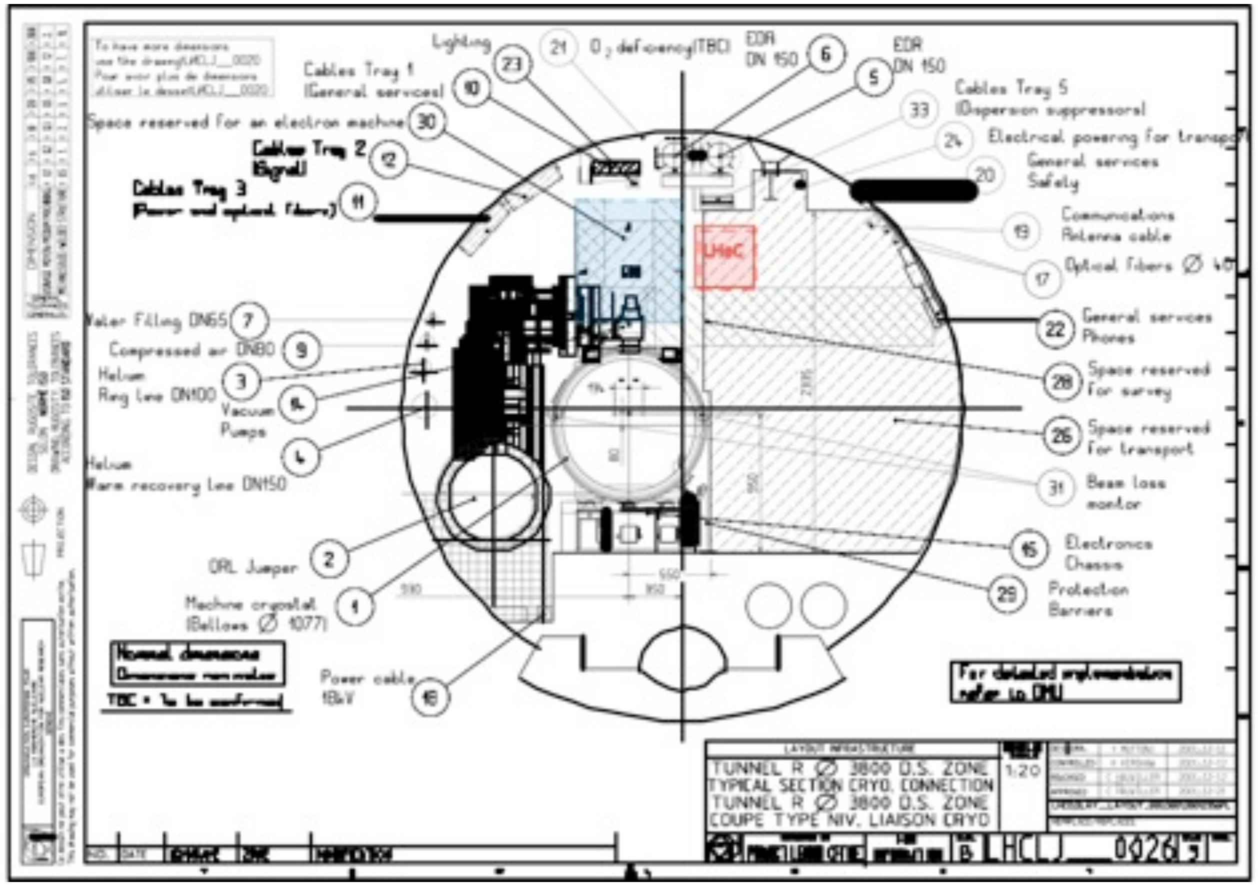


CMS longitudinal view



HF can be moved in parking position

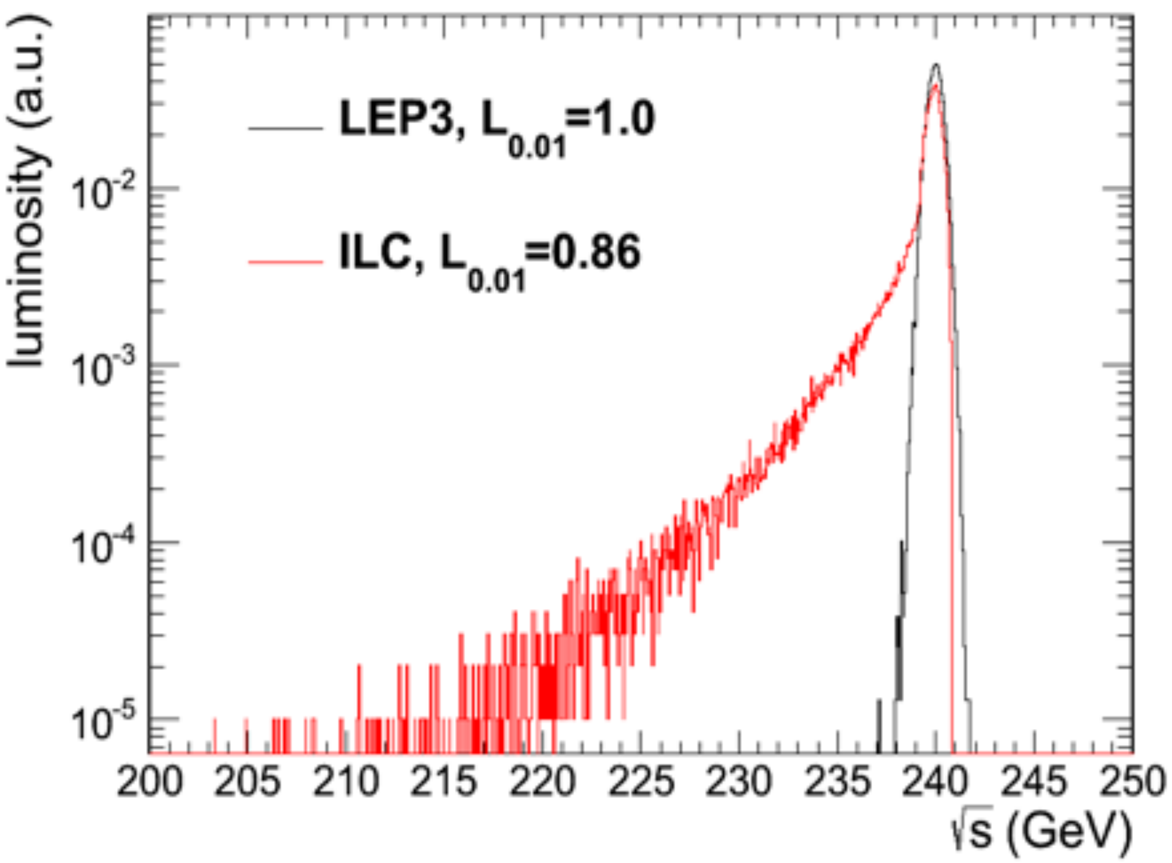
LEP3 and LHC



- LHeC shows that an e^- ring can coexist with LHC
  - Significantly smaller effective radius (LHC cyro jumpers)
- 5-10 years of LEP3 running in conflict with HL-LHC
- Experiment bypass for 2nd beam
- Synchrotron radiation damage to LHC equipment
- Different vertical plane would worsen ε^*_V

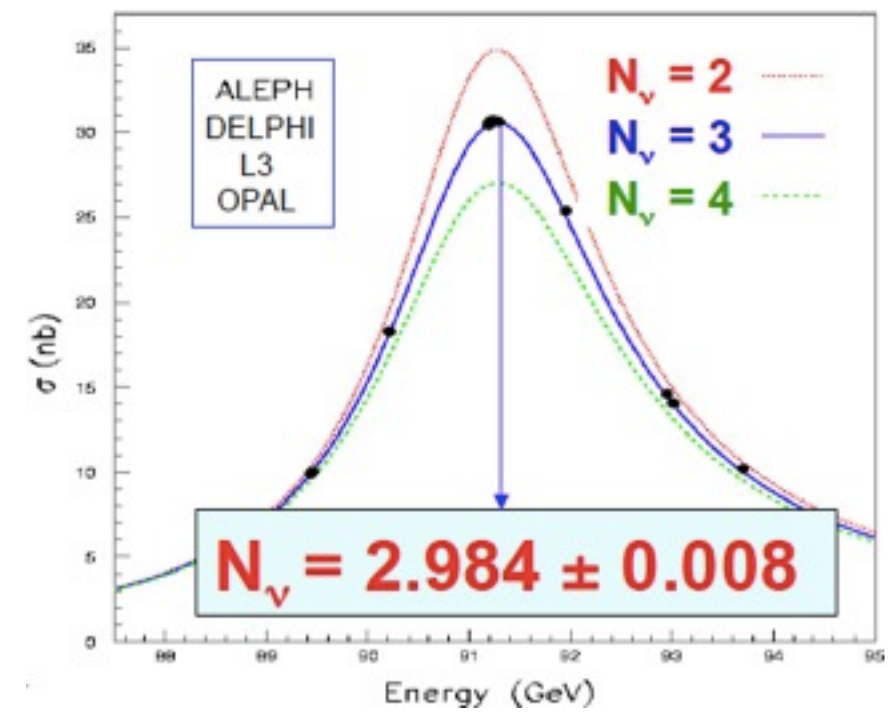
Performance summary

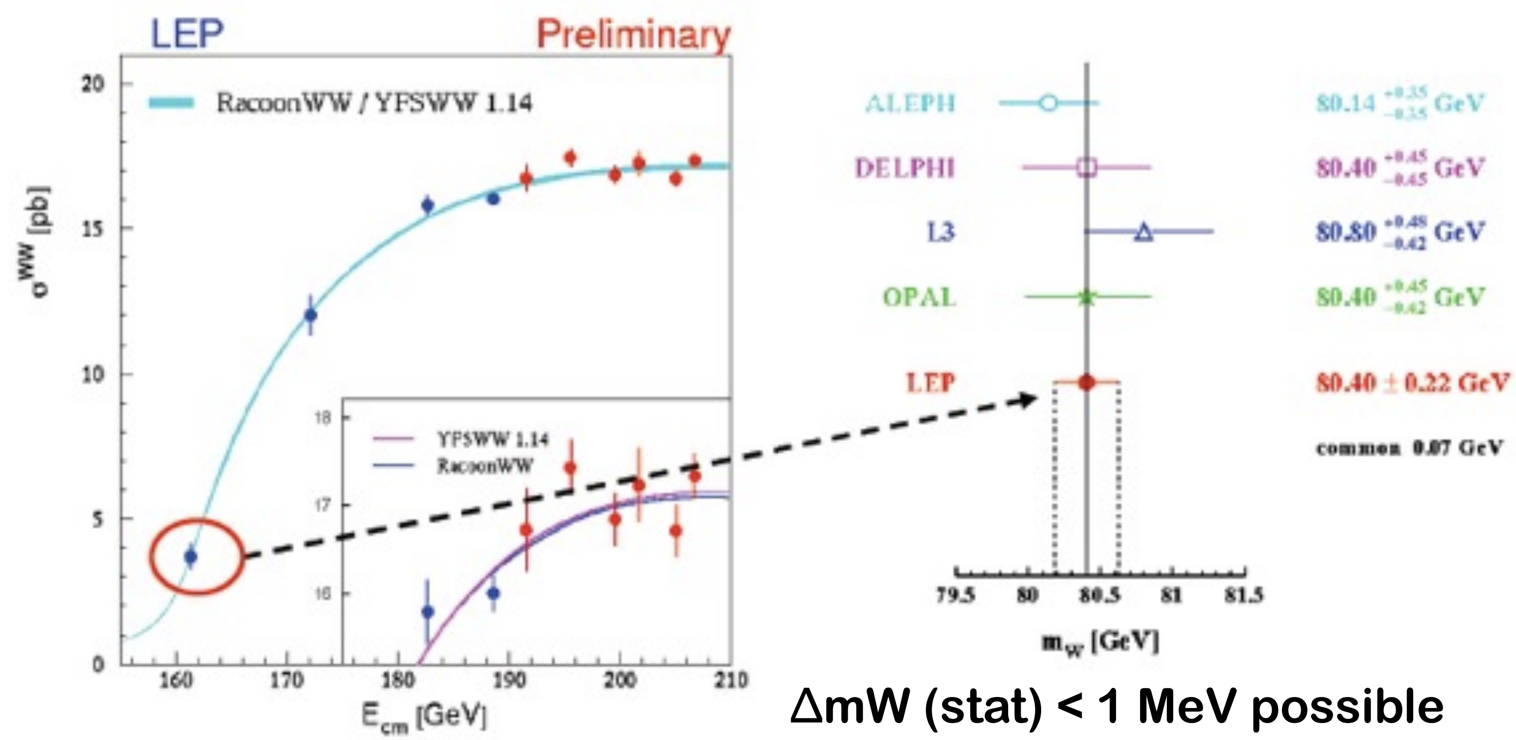
- Very narrow luminosity profile
- LEP3 luminosity @ $\sqrt{s}$=240 GeV: 10^{34} $cm^{-2}s^{-1}$
  - ~20k Higgs events per year per experiment
- Negligible pileup:
  - $\sigma(\gamma\gamma \to hadrons)$ = 15 nb, PU prob ~0.3%
- Lumi @ smaller $\sqrt{s}$:
- Performances scale for 4 experiments



Physics program of circular e$^+$e$^-$ collider

- GigaZ factory at $\sqrt{s} = m_Z$
  - 200x200 bunches, 5x10^{35} cm^{-2}s^{-1}
  - repeat LEP1 program every 10 min
  - 250x larger than LC GigaZ option
  - 5 ab^{-1} / experiment / year
  - ~10^{12} Z bosons
  - allow for polarized beams
- MegaWW factory at $\sqrt{s} = 2\ m_W$
  - 1x10^{35} cm^{-2}s^{-1}
  - 1 ab^{-1} / experiment / year
  - 4M W-pairs
  - 10^{5}x larger sample than LEP2
- Higgs factory at $\sqrt{s}$ = 240 GeV
  - 1x10^{34} cm^{-2}s^{-1}
  - 20000 Higgs bosons / year
  - 500 fb^{-1} / 5 year
- Top factory at $\sqrt{s}$ = 350 GeV
  - requires larger tunnel





ΔmW (stat) < 1 MeV possible

Physics program of circular e^+e^- collider

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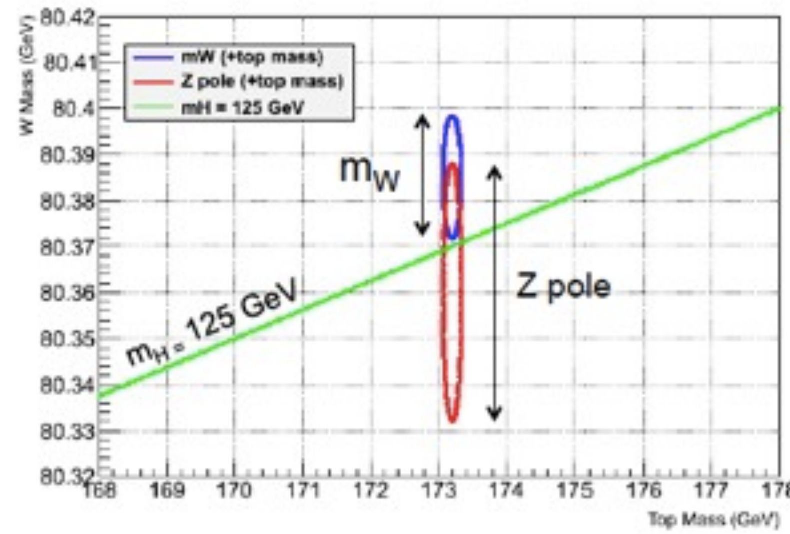
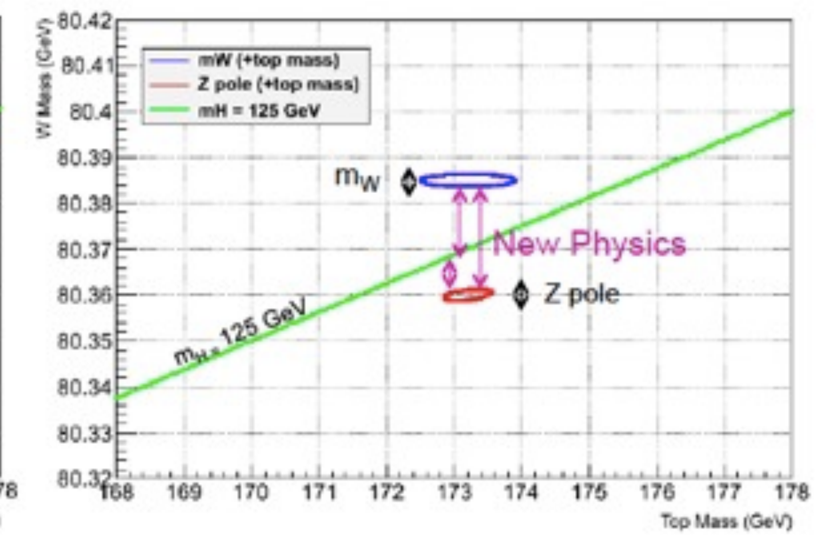
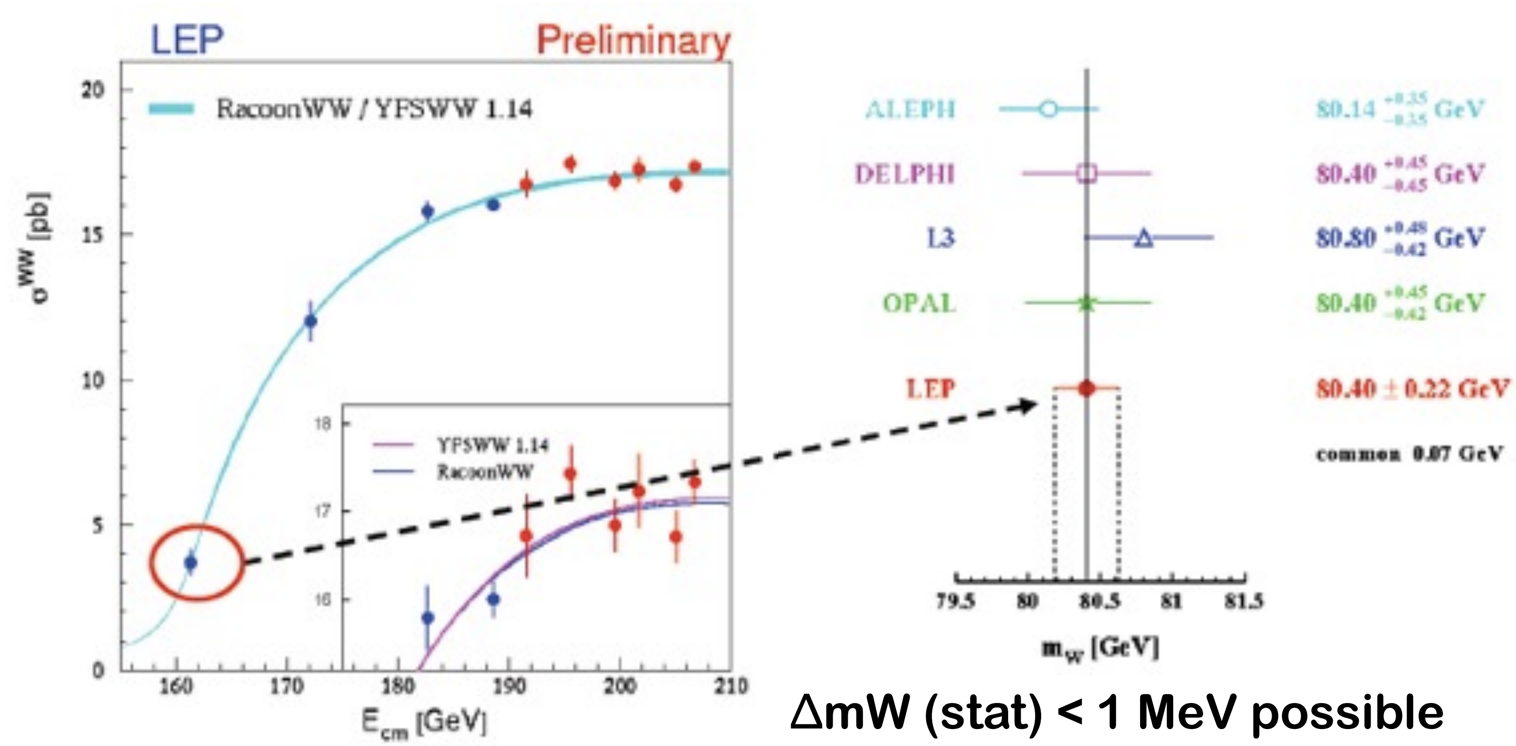


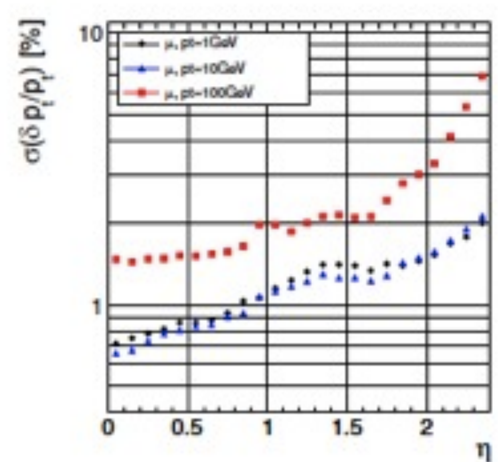




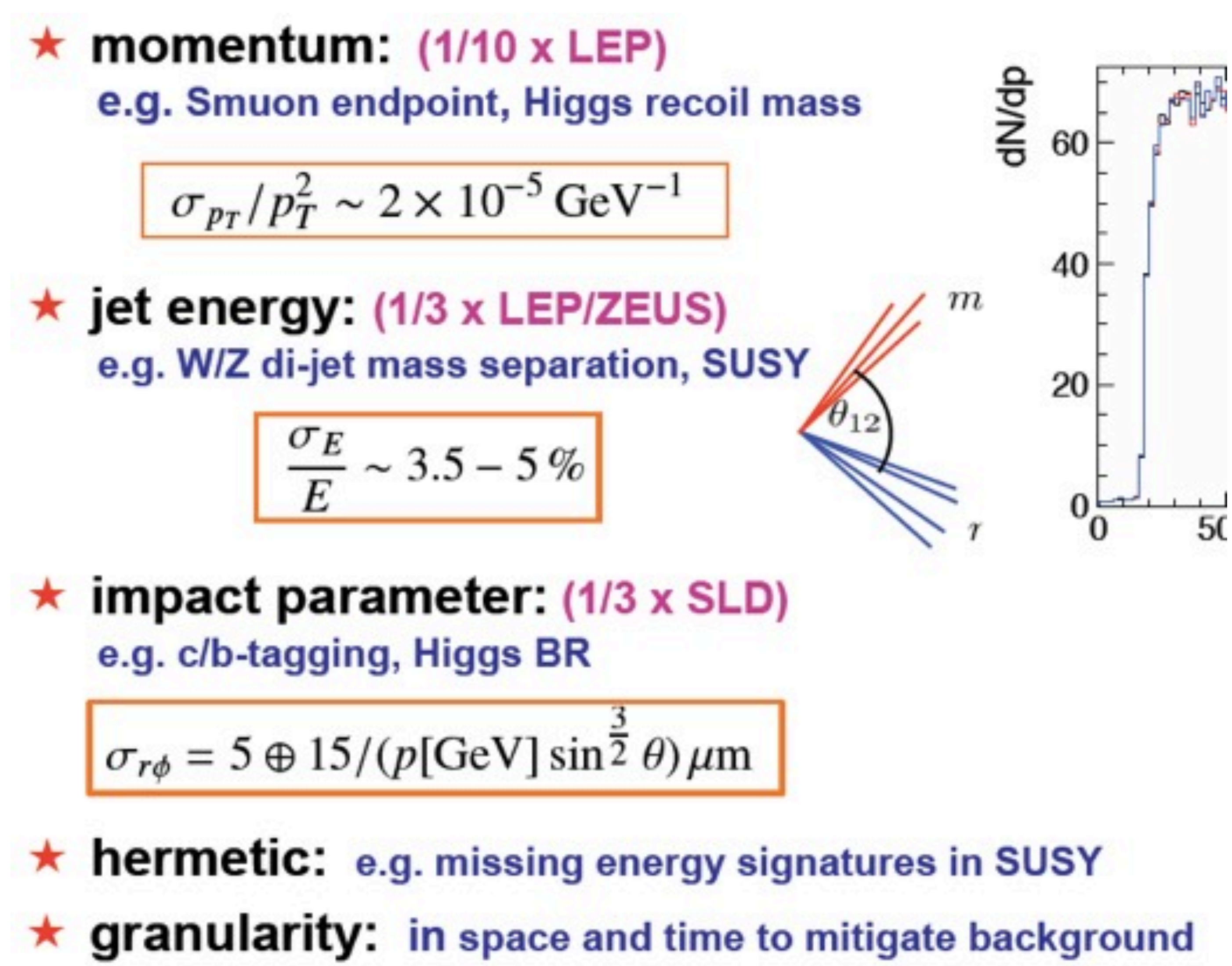
ΔmW (stat) < 1 MeV possible

CMS Performance

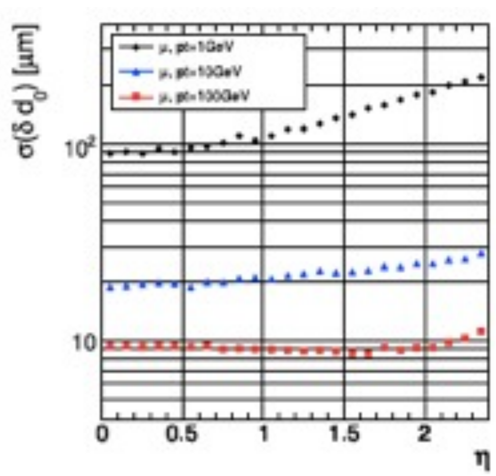
- **Comparing CMS with typical LC detector**
  - CMS typically 2-10 times worse than LC detector
  - good enough for Higgs program?
- **Momentum**
  - $\sigma_{pT}/pT = 0.7\%$ (10 GeV, central)



- **Jet energy**
  - $\sigma_E/E \sim 13\%$



- **Impact par.**
  - $\sigma_{d0} = 20\mu m$ (10 GeV, central)



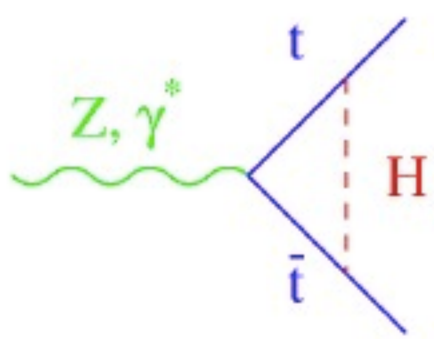
from Mark Thomson (CERN-PH Seminar)

Higgs Precision Measurements with CMS@LEP3

- Results are realistic and conservative
  - Full CMS detector is used throughout
  - Simulated 5 years of LEP3 or 500 fb^{-1}
  - No optimization of reconstruction was attempted
  - CMS upgrade detectors not included in simulation
    - upgrade pixel detector with 4 layer and lower material budget
  - No multivariate analysis was deployed
- In combination of two or four detectors, all detectors are assumed to be CMS
- Not all Higgs decay channels have been addressed
- Documentation
  - Prospective Studies for LEP3 with the CMS Detector, P. Azzi, C. Bernet, C. Botta, P. Janot, M. Klute, P. Lenzi, L. Malgeri, M. Zanetti, arXiv:1208.1662
  - Update will be available mid Oct.

Higgs factory at $\sqrt{s}$ = 240 GeV

- 100.000 HZ events / experiment
- Out of reach
  - Hvv cross section to small
  - Top-pair production



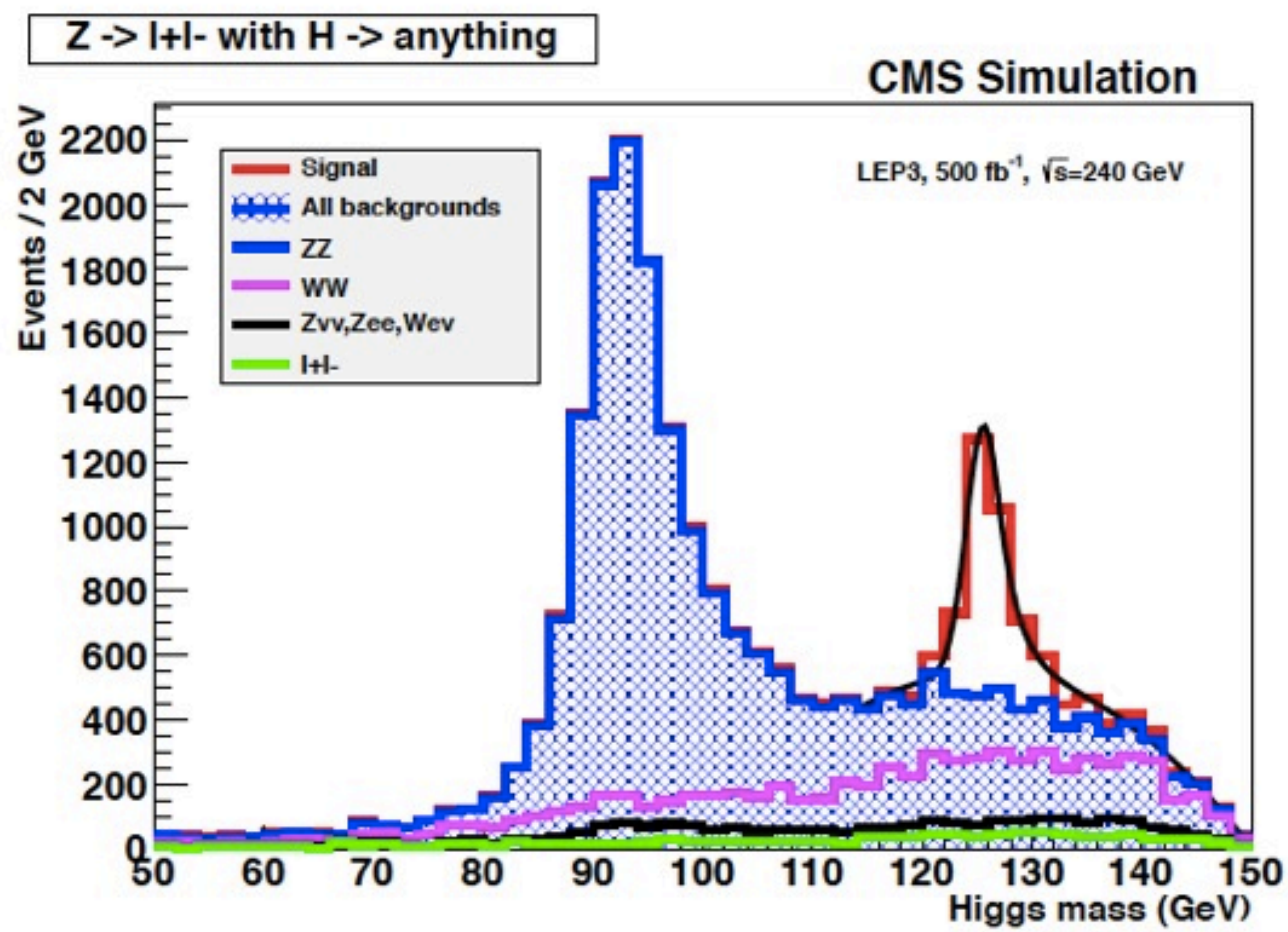
- Higgs self coupling

Decay	Events
bb	58000
ττ	6400
cc	2800
μμ	22
WW	22000
gg	8200
ZZ	2600
γγ	260
Zγ	160
X^0X^0	???

Measurement of $e^+e^- \to ZH$ cross section

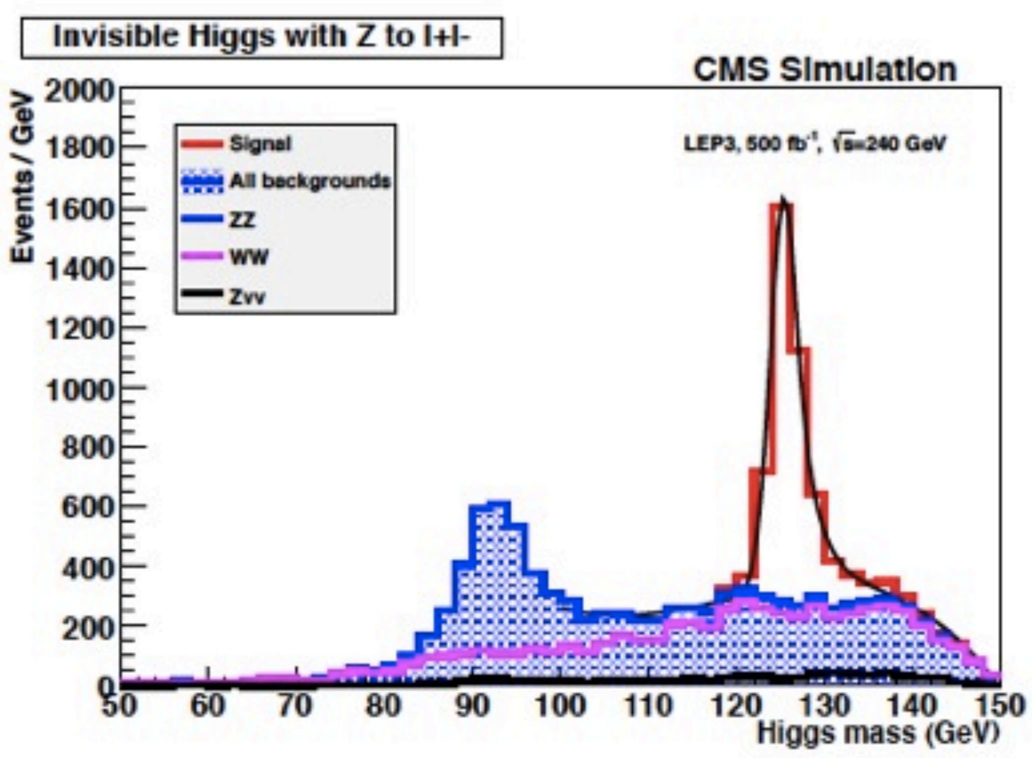
- Model-independent measurement with $Z \to e^+e^-$, $\mu^+\mu^-$
  - Two oppositely-charged same-flavor leptons
  - Invariant mass within 5 GeV of Z mass
  - Reject radiated events (ISR) with pT, pZ, acoplanarity cuts and photon veto
  - Fit Higgs contribution from recoil mass spectrum
  - Improvements possible

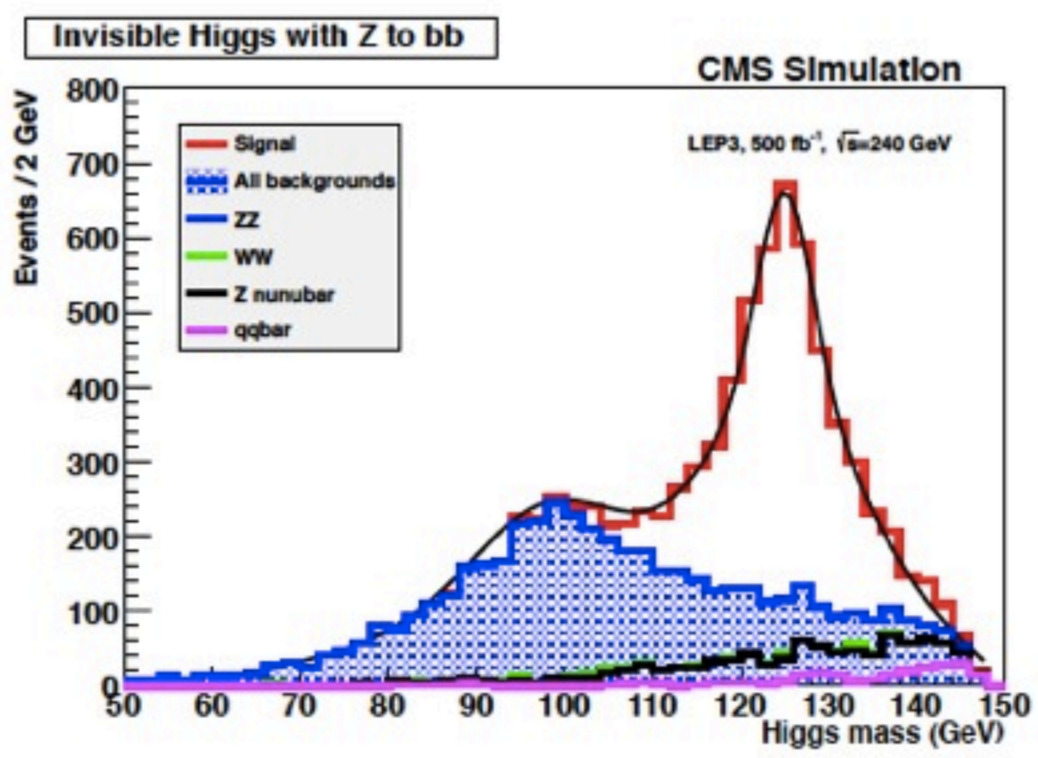
Combined precision of 1.9% on σ_{HZ} for 2xCMS, 0.9% on g_{ZZH}.



Measurement of invisible Higgs decays

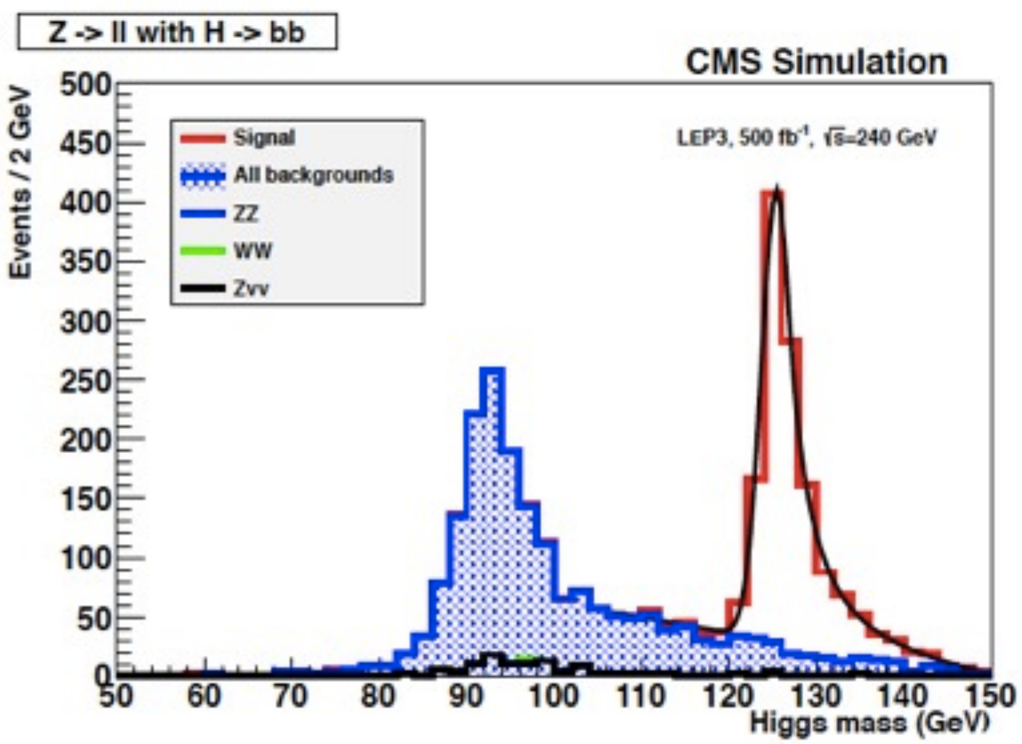
- Same approach as before
  - with requirement that event consists of only two leptons
    - show mass recoiling the two lepton system
  - repeat the analysis with Z ➜ bb
    - force event to two jets
    - invariant mass within 15 GeV of Z mass
  - we can exclude BR to invisible of ~1%

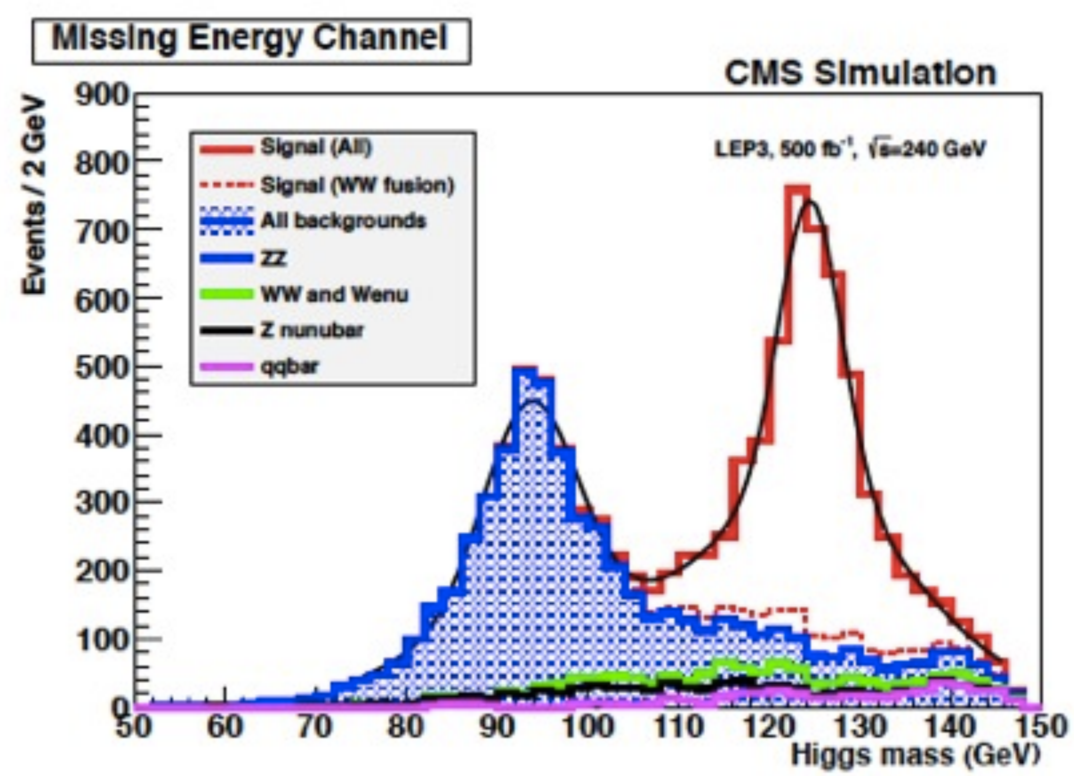




Measurement of σ_{HZ} x BR (H➜bb)

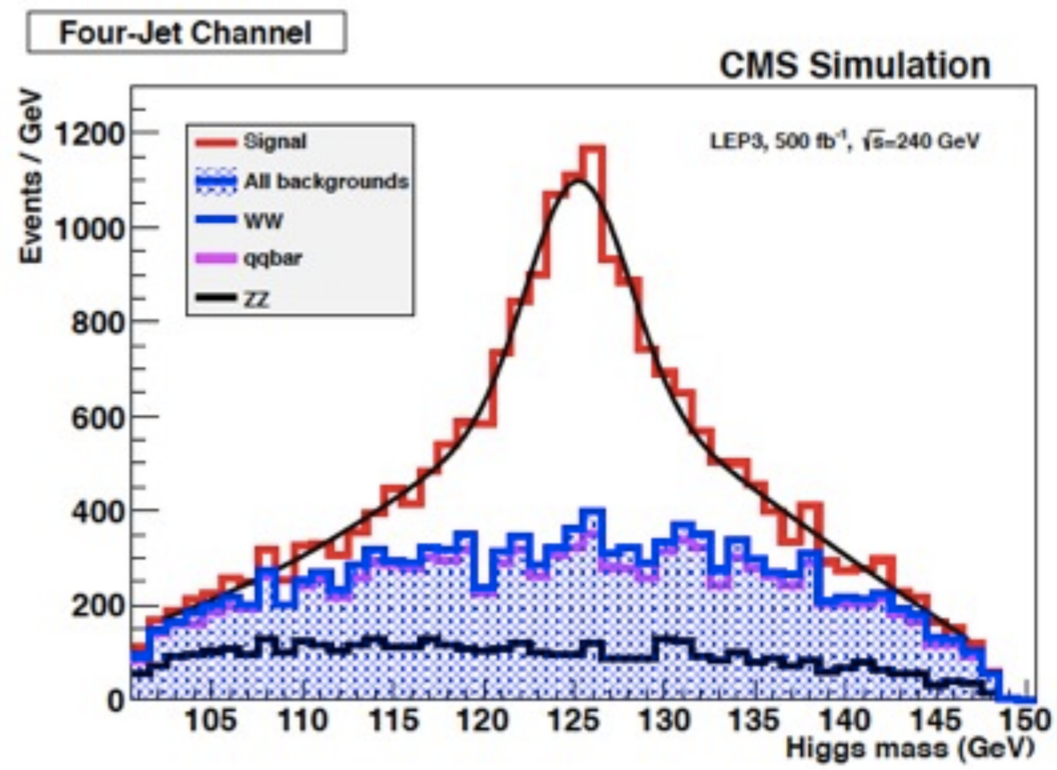
- Leptonic final states, Z ➜ e^+e^-, $\mu^+\mu^-$
    - exact same selection as before
    - force the rest of the event to form two jets and apply a tight b tagging
    - precision of 1.5% overall on σ_{HZ} x BR (H➜bb)
- Missing energy final state, Z ➜ νν
    - reuse invisible Higgs search with Z ➜ bb
    - substitute missing mass visible mass
    - precision of 1.5% overall on σ_{HZ} x BR (H➜bb)





Measurement of σ_{HZ} x BR (H➜bb)

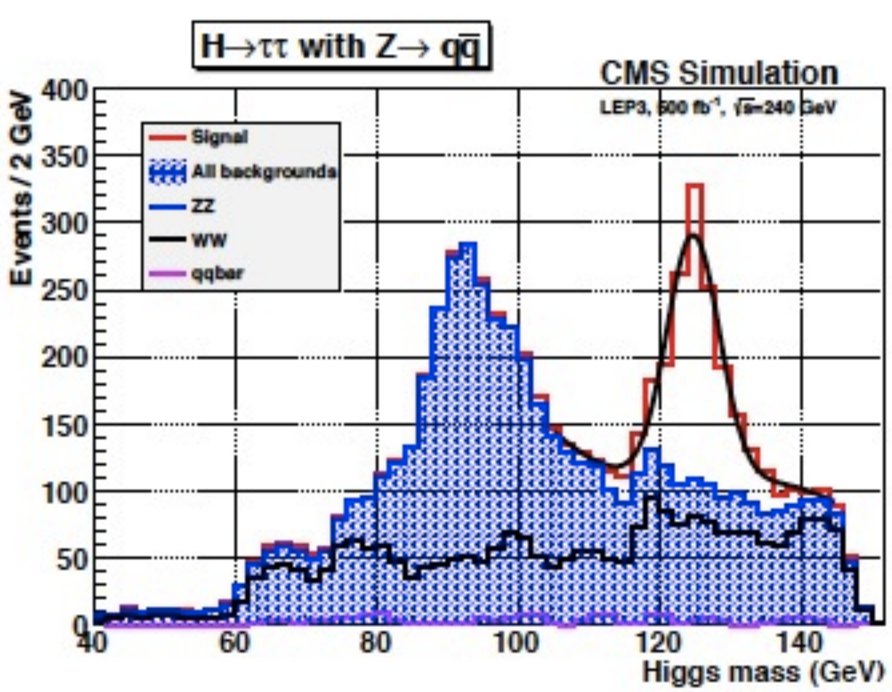
- Four-jet channel: Z ➜ qq
  - Kinematic selection
    - anti-kT particle flow jet, number of jets >= 4
    - for N_{Jets} > 4, recombined the jet pair with the smallest mass
    - M_{tot} > 180 GeV
    - fix jet direction p/E, and rescale jet energies to conserve energy (240 GeV) and momentum (0,0,0), and require all rescaled energies to be positive
    - reject WW and ZZ: $\sqrt{(m_{12}-m_V)^2+(m_{34}-m_V)^2} > 10$ GeV, for all 12, and 34 combinations
    - $m_{12} > 100$ GeV (Higgs candidate), $80 < m_{34} < 110$ GeV (Z candidate)
    - resolve ambiguity by selecting on b-tag values of the jets and require $b_1+b_2 > 0.95$ (value of secondary vertex tagger)
  - Fit a Gaussian + 3rd order pol to $m_{12}+m_{34}-m_Z$
  - precision of 1.3% overall on σ_{HZ} x BR (H➜bb)

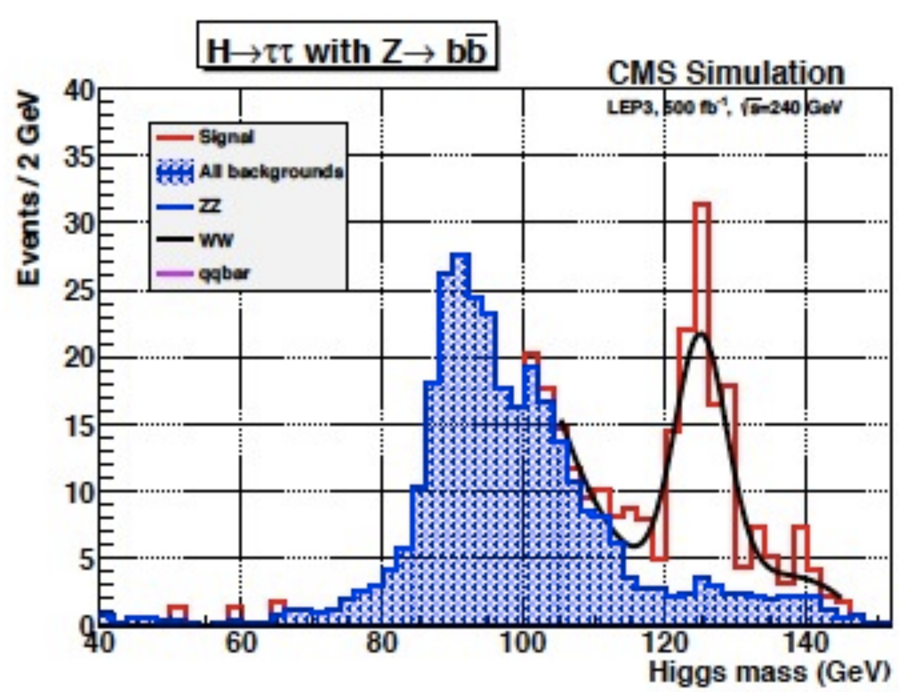


Combined precision of 0.8% on σ_{HZ} x BR (H➜bb) for 2x CMS

Measurement of σ_{HZ} x BR ($H \rightarrow \tau\tau$)

- Analysis similar to bb decay
  - substitute b-tagging for tau-tagging
  - used hadronic and leptonic Z decays
    - missing energy channel does not allow mass determination

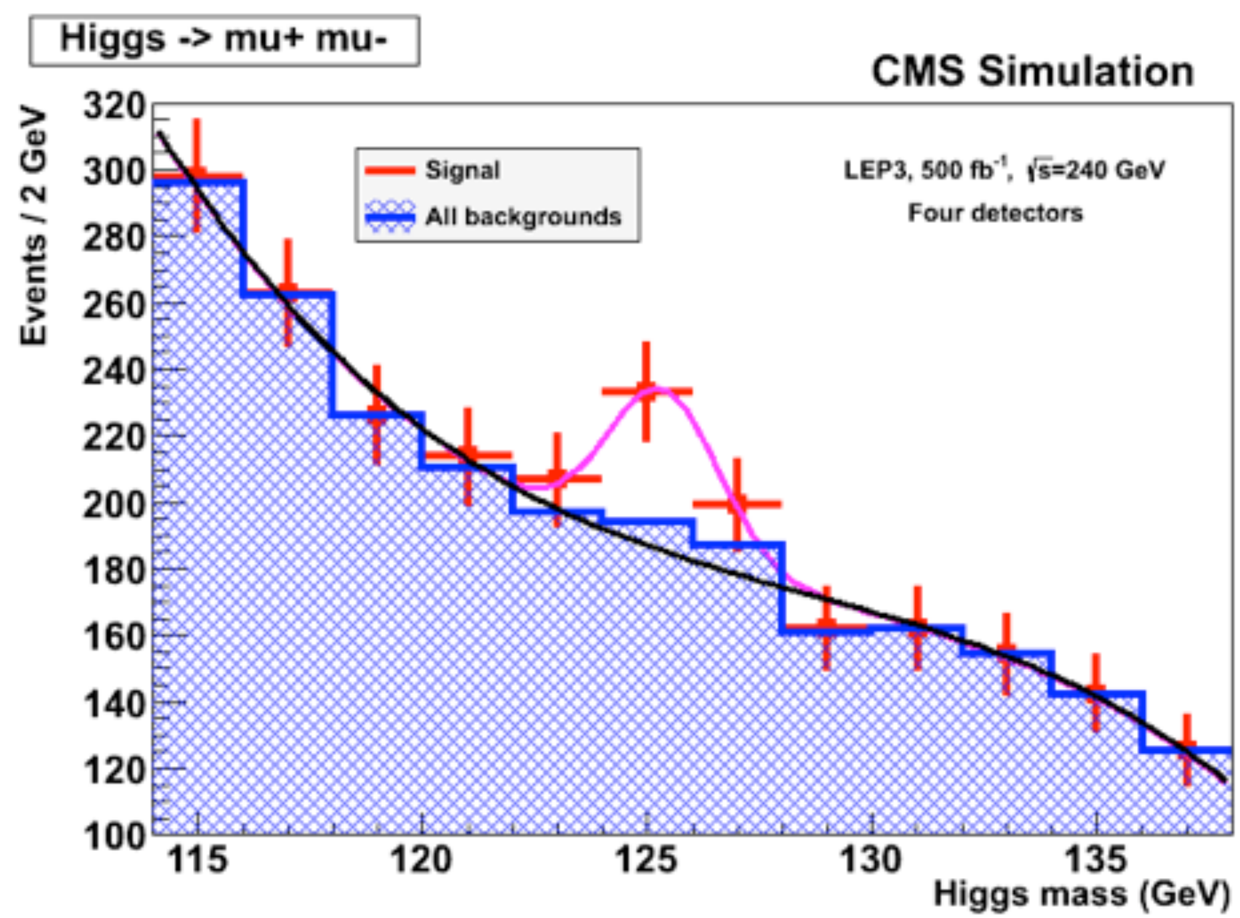




Combined precision of 3.0% on σ_{HZ} x BR ($H \rightarrow \tau\tau$) for 2x CMS

Measurement of σ_{HZ} x BR (H➔μμ)

- 22 H ➔μμ events expected in 500 fb^{-1}
  - four detectors help! 90 events
- two oppositely changed muons
- mass recoiling to muon pair consistent (15 GeV) with Z mass
- reject Z ➔ νν and WW ➔ lνlν by requiring 2 jets
- analyze di-muon mass distribution
- some potential for improvement using smart event classification
- expect ~4σ excess



Combined precision of 33% on σ_{HZ} x BR (H➔μμ) for 4x CMS

Summary of measurements

	ILC	LEP3 (2)	LEP3 (4)
σ_{HZ}	3%	1.9%	1.3%
$\sigma_{\mathrm{HZ}} \times \mathrm{BR}(\mathrm{H} \to \mathrm{b\bar{b}})$	1%	0.8%	0.5%
$\sigma_{\mathrm{HZ}} \times \mathrm{BR}(\mathrm{H} \to \tau^+\tau^-)$	6%	3.0%	2.2%
$\sigma_{\mathrm{HZ}} \times \mathrm{BR}(\mathrm{H} \to W^+W^-)$	8%	4.4%	3.1%
$\sigma_{\mathrm{HZ}} \times \mathrm{BR}(\mathrm{H} \to \gamma\gamma)$	?	9.5%	6.6%
$\sigma_{\mathrm{HZ}} \times \mathrm{BR}(\mathrm{H} \to \mu^+\mu^-)$	–	–	33%
$\sigma_{\mathrm{HZ}} \times \mathrm{BR}(\mathrm{H} \to \mathrm{invisible})$	?	1%	0.7%
g_{HZZ}	1.5%	0.9%	0.6%
g_{Hbb}	1.6%	1.0%	0.7%
$g_{\mathrm{H}\tau\tau}$	3%	2.0%	1.5%
g_{Hcc}	4%	?	?
g_{HWW}	4%	2.4%	1.7%
$g_{\mathrm{H}\gamma\gamma}$	?	4.9%	3.4%
$g_{\mathrm{H}\mu\mu}$	–	–	16%

We are refining results and adding channels

Summary of measurements

	ILC	LEP3 (2)	LEP3 (4)	LHC
σ_{HZ}	3%	1.9%	1.3%	–
$\sigma_{HZ} \times BR(H \to b\bar{b})$	1%	0.8%	0.5%	–
$\sigma_{HZ} \times BR(H \to \tau^+\tau^-)$	6%	3.0%	2.2%	–
$\sigma_{HZ} \times BR(H \to W^+W^-)$	8%	4.4%	3.1%	–
$\sigma_{HZ} \times BR(H \to \gamma\gamma)$	?	9.5%	6.6%	–
$\sigma_{HZ} \times BR(H \to \mu^+\mu^-)$	–	–	33%	–
$\sigma_{HZ} \times BR(H \to \text{invisible})$	?	1%	0.7%	–
g_{HZZ}	1.5%	0.9%	0.6%	13%
g_{Hbb}	1.6%	1.0%	0.7%	21%
$g_{H\tau\tau}$	3%	2.0%	1.5%	13%
g_{Hcc}	4%	?	?	?
g_{HWW}	4%	2.4%	1.7%	11%
$g_{H\gamma\gamma}$	?	4.9%	3.4%	6%
$g_{H\mu\mu}$	–	–	16%	25%

LHC results need to be revisited

What are the options for a Higgs factory?

- Discussions on future capabilities for HEP in the context of "European Strategy Preparations Group" (workshop in Krakow Sep 2012) and "Snowmass 2013"
- Capabilities for future Higgs measurements
  - proton-proton: LHC, HE-LHC, HL-LHC
  - e+e-: circular, linear
  - muon collider
  - photon collider
- Consider cost, likelihood for success and benefits (physics potential, R&D, ...)
- Circular e^+e^- machine is an interesting opportunity

Summary & remarks

- Circular e+e- is an interesting opportunity
  - very affordable price tag for the community (factor of 4-8 lower than ILC)
- Excellent physics program
  - challenge the standard model consistency
  - Higgs precision physics
- At CERN
  - cohabit with LHC, LHeC in the LEP tunnel (LEP3)
  - use of existing infrastructure including ATLAS and CMS detectors
- In a new tunnel (e.g at Fermilab)
  - larger energy reach
  - potential for future proton-proton machine
- Project should be continued at least towards a TDR

- First historic discovery made at the LHC
  - Observation of new boson near 125 GeV
  - ATLAS and CMS observed it independently
  - It behaves like the Standard Model Higgs boson
- Fantastic experience for me personally, teams involved and a truly great moment for physics
- Looking forward: circular e^+e^- collider interesting option to characterize the new state